

**Report No. UT-00.01**

# **I-15 National Test Bed For Advanced Transportation Research And Testing**

## **Phase 3 Program Report**

**Utah Transportation Center  
Utah Department of Transportation  
Federal Highway Administration**

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# UDOT Research & Development Report Abstract

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<b>16. Abstract</b> Phase 3 of a transportation engineering research program is detailed in this report. The program will perform research during the design/build reconstruction of over 16 miles of Interstate 15 in Salt Lake County, Utah. The program is funded through a research grant from the FHWA authorized by TEA-21 legislation specifically targeted to the I-15 National Test Bed Consortium. The program is administered jointly by the Utah Transportation Center, the Utah Department of Transportation and the Federal Highway Administration. Included in the program are technology transfer efforts beyond distribution of the final report. This program follows Phases 1 and 2, a summary of which is also given. In addition, a summary is given of the steps taken to accommodate research in a design/build environment. Detailed work plans are given for 10 research studies that are to be performed under the Phase 3 program. These ten studies are: <ul style="list-style-type: none"> <li>· Column-to-Bent Shear Tests</li> <li>· Experimental Determination of Dynamic Characteristics of New Bridges</li> <li>· Long-Term Structural Monitoring of Post-Tensioned Spliced Girders and Deck Joints</li> <li>· Computer Modeling and LRFD Design Equation Verification for Curved Steel Girder Bridges</li> <li>· Strong Motion Instrumentation of I-15 Bridges</li> <li>· Long-Term Evaluation of FRP Composites for Bridge Retrofit</li> <li>· Ult. and Residual Capacity of Geopier Foundations Subjected to Uplift and Compressive Loads</li> <li>· Long-Term Evaluation of MSE Walls on Soft Foundations</li> <li>· Corrosion Evaluation of Original I-15 Steel Pipe Piles</li> <li>· Full-Scale lateral Pile Cap and Backfill Load Testing</li> </ul>			
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## **Introduction**

A unique research opportunity was created as a result of the Interstate 15 reconstruction in Salt Lake County, Utah. Influenced by the present inadequacies of the system, the Utah Department of Transportation (UDOT) is replacing approximately 16.5 miles of interstate freeway in the Salt Lake Valley over a period of four years. This reconstruction will require more than 5 million cubic yards of fill material and 2.5 million square yards of concrete pavement. In addition, ten urban interchanges will be rebuilt and more than 125 bridges will be replaced. Wasatch Constructors, a consortium with headquarters in Phoenix, Arizona, was chosen as the design/build contractor. The expected completion date for the project is July, 2001, in time for the Winter Olympics that will be hosted by Salt Lake City in 2002.

This section of Interstate 15 was built in the early 1960's, at which time there were about 380,000 residents in the Salt Lake Metro area. The population has grown to over one million, which when combined with interstate traffic produces over 600,000 vehicles per day on this part of the corridor. To handle this volume, the corridor will be widened from three to six lanes in each direction, including HOV and auxiliary lanes. Also, over 130 traffic signals on primary and secondary arterials throughout the valley will be integrated into an advanced traffic management system (ATMS) that will be jointly coordinated between three public agencies.

In addition to being functionally deficient, the bridges being replaced are also structurally deficient. Two factors contribute to this deficiency. First, the corridor was built prior to the development of modern seismic design criteria. Salt Lake City is located in a seismically active area. Second, severe weather and winter maintenance activity has resulted in significant deterioration in many areas.

## **Research Opportunity**

This unique project presents an opportunity to address vital questions regarding the many innovative processes, techniques, designs and materials that are expected to be employed in the new construction, and the design capacity and durability of the existing facilities that will be demolished and removed.

Due to the uniqueness of this occurrence, UDOT actively explored various research opportunities. This included the solicitation of research ideas and work plans from anyone interested in participating. A national workshop was held on May 12, 1997, in Salt Lake City to identify and develop a research agenda related to the I-15 Reconstruction Project. Experts from around the country attended and proposed research topics related to bridges, foundations, pavements, materials, construction, maintenance, planning, traffic, safety, and intelligent transportation systems (ITS)

At this forum, both research needs and potential funding sources were identified. Topic areas considered included full-scale testing on existing structures that were being taken out of service, and monitoring new materials, processes, construction techniques and methods that were being employed and practiced during the reconstruction project. Many of these research topics were

incorporated into Phase 1 and Phase 2 of the Test Bed research. This document describes those that will be part of Phase 3.

## **I-15 National Test Bed**

To achieve the goals of this research agenda, the *I-15 National Test Bed for Advanced Transportation Research and Testing* (Test Bed) consortium was established. The Utah Department of Transportation (UDOT) entered into a Memorandum of Understanding with the three major universities in Utah having civil engineering research programs, Brigham Young University (BYU) in Provo, University of Utah (U of U) in Salt Lake City, and Utah State University (USU) in Logan. These three universities collectively are referred to as the Utah Transportation Center. The partnership of the Federal Highway Administration (FHWA) provided national perspective to this consortium through funding initiatives and by helping to guide the objectives and scopes of the individual research projects. Other ex-officio partners to the test bed include Wasatch Constructors, Penhall Company, Terracon, numerous consultants and many other private contributors. The combination of government, academic and private sector interests created a very innovative environment and resource pool to get the most possible from the limited funding available. As part of this ongoing research program, the Test Bed consortium has developed the work plans for this Phase 3 program as *earmarked* and appropriated under the Federal TEA-21 legislation for the 2000 fiscal year.

The Test Bed consortium is directed by an executive committee made up of the consortium universities, UDOT and the FHWA. Current voting members of the committee and their affiliation are as follows:

<b>Name</b>	<b>Affiliation / Title</b>
Doug Anderson, Chair	UDOT, Director of Research
Loren Anderson	USU, Civil Engineering Department Chair
Jon Bischoff	UDOT, Geotechnical Specialist Engineer
William Gedris	FHWA, Structural Engineer
Larry Reaveley	UofU, Civil Engineering Department Chair
Boyd Wheeler	UDOT, Assistant Chief Structural Engineer
Leslie Youd	BYU, Civil Engineering Department Chair

Kevin C. Womack (USU) is an ex-officio member of the committee and serves as the administrator. The executive committee makes the final decisions regarding priorities of proposed research studies that would be conducted under this program on the I-15 corridor using the allocation of the research funds received from the FHWA through TEA-21 legislation.

## **Establishing an I-15 Research Agenda**

The nature of the design/build process is intended to foster efficiency while maintaining a high level of quality. Therefore, the contractor must inherently be allowed some flexibility to institute changes in the design and construction schedule as the work progresses. However, the focus and degree of flexibility exercised by the contractor is not necessarily conducive to performing research in a design/build environment.

In addition to this inherent constraint, a number of other preconceived notions and institutional barriers had to be overcome in order to conduct research on the I-15 Reconstruction Project. Several steps were undertaken to mitigate conflicts and to topple barriers.

First, support was developed within the Department for a research agenda. This was done by reaching a degree of unanimity between the research community and the end users as to what research would be useful and feasible to perform. The I-15 project team had to be convinced that a research agenda would not cause adverse risk to the project budget or schedule. Parallel to these efforts, funding sources were sought to support a research agenda.

Once the research agenda was recognized as both feasible and desirable, a provision was included in the design/build request for proposals that notified contractors that the Department intended to conduct research and invited their cooperation and partnership in its accomplishment. One of the selection criteria was the degree of willingness exhibited by bidding contractors to assume a partnering stance. The successful contractor did in fact submit the most favorable plan for partnering on many issues, including research.

The final step in securing the research agenda was establishing a research management protocol between the contractor, UDOT's I-15 Project Team and UDOT's Research Division. The objectives of the protocol were to protect the contractor and the project from overruns in cost or schedule that could be attributed to research activities, as well as to assure that safety and other risk management issues would be addressed by the research participants. Objectives from the research perspective were to allow collaborative agreements with subcontractors and other third parties, and to reduce bureaucracy by permitting decision making to occur at the lowest level possible. After substantial negotiations the following protocol was agreed upon and included in all research contracts:

- The research activity shall not impact the cost of the D/B project;
- The research activity shall not impact the critical path schedule of the D/B project;
- If conflicts in the work schedule inadvertently arise between research activities and that of the D/B project, work under the D/B project shall take precedence;
- Research schedules and employment of subcontracts for research activities shall be coordinated with and agreed upon by both the UDOT and the contractor at the segment (lowest) level;
- The contractor's segment project managers shall determine coordination protocols to be followed in their segments; and,
- All personnel associated with or employed as part of the research activity shall undergo a safety orientation provided by UDOT or the contractor. In addition, if research activities are conducted immediately adjacent to or on railroad property or right-of-way, these personnel shall undergo a safety orientation approved by the railroad. The research participants shall agree to abide by and enforce the safety requirements of UDOT, the contractor, and the railroad as applicable.

While these steps were key to opening up the possibility for research to occur on the I-15 corridor during reconstruction, several other factors contributed to its ultimate success. One of these was collaborations with strategic subcontractors associated with the D/B project,

particularly those responsible for demolition and for geotechnical testing. In many cases these contractors had control of both the work site and the schedule, which made their participation almost mandatory. Also, they were more highly motivated than the general contractor to take the risks associated with the relatively smaller sized research activities in order to add to their work volume. The downside was that their participation was not always obtained at the lowest possible cost.

Another factor that had to be addressed was UDOT's research contracting process. Prior to this program, contracting for research was performed by either the Consultant Services Division or the Procurement Division of UDOT. Their processes were designed either for architect/engineer services or large annual purchases of equipment and materials. Also, the Research Division had to compete with many others in the department for the available resources of these two divisions. To be both more responsive and more flexible under the design/build scenario, the Research Division took over the contracting task for research projects, greatly facilitating working with the subcontractors and others on time critical research activities under this program.

## Phase 1 and Phase 2 Programs

In addition to federal funding through an *earmark* in the TEA-21 legislation and subsequent appropriations, researchers were encouraged to seek out innovative funding sources for their studies. This was done to a remarkable extent under Phases 1 and 2 of the I-15 National Test Bed Research Program. A complete description of Phases 1 and 2 are given in Report No. UT-99.03 (Phase 1) and Report No. UT-99.04 (Phase 2). A brief synopsis of the individual research activities conducted under Phases 1 and 2 are given below:

- **Full Scale Beam/Column Reinforcement with Carbon Fiber Composites, Phases 1 and 2** - A series of push-over tests were performed on I-15 bridge bents at South Temple, both with and without strengthening provided by carbon fiber composite reinforcement. The information will be used to understand the capacity of existing bridges, and the use of composites in retrofitting bridge components. (U of U);
- **Bridge Deck Reinforcement with Carbon Fiber Composites** - Bridge deck specimens taken from structures scheduled for demolition on I-15 are being used to test the strength gain and fatigue resistance obtained from composite reinforcing. Various vendors have been evaluated in a series of laboratory tests. (U of U);
- **Forced Vibration Testing, Phases 1 and 2** - Prior to demolition, a number of existing bridges on the I-15 corridor were vibrated, both before and after various levels of damage states were inflicted, and the resulting responses in the bridge components were measured. A new non-destructive method may be developed by analyzing bridge signatures. (USU);
- **Geopier Foundation Testing, Phases 1 and 2** - An evaluation of Geopier aggregate piers was conducted at the South Temple test site on I-15 during the pushover testing. These evaluations included lateral, uplift, and compressive loads on Geopiers, lateral loads on shallow foundations, and the soil-structure interactions occurring at the foundation level as a result of lateral loads on existing bridge bents. (U of U);



- **Wick Drain Performance Delay-** Instrumentation was placed to evaluate the effects of wick drain spacing and foot configurations on the delay caused by installation of wick drains in fine grained materials. (Richard Landau);
- **Ground Penetrating Radar for NDE of Bridge Decks-** Specimens of bridge decks that were being taken out of service were extracted before demolition and shipped to the FHWA's research facilities in McLean, Virginia. There, they will be used to help calibrate various GPR technologies including the HERMES system. (FHWA);
- **Bridge Superstructure and Substructure Corrosion-** Selected bridges being taken out-of-service are being studied to determine the effectiveness of various corrosion prevention and repair methodologies including epoxy coated rebar, precast beam end coatings, cathodic protection, and bonded overlays. (Corrosion Control Technology);
- **Field Testing and Computer Modeling of a Curved Steel Girder Bridge, Phase 1** - One of the bridges being taken out of service and replaced during the I-15 Reconstruction Project was a single span supported by curved steel girders. Since the exact behavior of curved steel girder bridges has not been entirely understood, this bridge was tested prior to demolition. The structure response was measured under various static and rolling loads. In addition, the dynamic signature of the bridge was established. Future phases of the study are expected to develop computer models that will replicate the measured field performance. Also, the measured results and computer models will be compared with that predicted using the AASHTO LRFD design standards. (USU)
- **Lateral Loads on Pile Groups, Phase 3** - Modern approaches to earthquake engineering dictate that the deformations of structure foundations be compliant with that of the superstructure in order to avoid damage and potential collapse. Hence, rigid foundation systems are avoided in favor of flexible ones. One economical way to achieve a flexible foundation is to use the lateral capacity of piles, which mobilize both the pile's bending capacity and the passive resistance of the earth that it is embedded in. However, very little is known regarding the capacity of these combined support systems.

Part 1 of this study evaluated the static and dynamic lateral capacity of a 3x3 group of 12-inch diameter piles at 3x diameter spacing (see Report No. UT-00.03 and other journal publications). Part 2 of the study looked at the lateral capacity of pile groups under induced liquefaction conditions. Part 3 expanded the investigation to include larger diameter piles, rectangular pile groups and spacings other than 3x diameter. (BYU); and,

- **Existing Column / Beam Evaluation, Phase 1** - The existing bridges on the I-15 corridor provide an excellent opportunity to evaluate the strength lost due to corrosion and deterioration. Phase 1 of this study extracted sections of columns and bents prior to bridge demolition. Phase 2 will perform a laboratory investigation of their strength. (BYU).

### Phase 3 Program

Phase 3 of the I-15 National Test Bed Research Program consists of some new studies as well as some extensions of other studies that were performed under Phases 1 and 2. These extensions of earlier studies either expanded the number of parameters that had been considered or demonstrated and implemented proof-of-concept findings. The final list of projects was a result of extensive reviews and negotiations between UDOT, the FHWA and the university research community. Projects were prioritized based on several factors, including applicability to the national strategic research agenda, urgency dictated by the timing of the I-15 Reconstruction Project, and availability of funds.

Table 1 summarizes the funding for Phase 3. The primary federal portion of these funds is provided by a special appropriation under TEA-21 legislation that recognized the unique opportunity afforded by the I-15 Reconstruction Project. These funds were won through a collaborative effort between UDOT and their university research partners. As can be seen, these federal funds are highly leveraged (52%) with other matching funds, including the 20% state match for the TEA-21 appropriation, UDOT's annual state and federal (SPR) research programs, UDOT Construction funds, FHWA Innovative Bridge Research funds, and funds from the private sector.

**Table 1**  
**I-15 National Test Bed, Phase 3**  
**Research Program Funding Sources**

<b>Funding Sources</b>	<b>Funding Amounts</b>	<b>Total Funding</b>
<b>TEA-21 FY 2000 Funds:</b>		
FHWA Research	\$750,000	
State Match	\$187,500	
Subtotal TEA-21 Funds		\$937,500
<b>Other Funding Sources:</b>		
State Construction	\$165,600	
Planning & Research (SPR) w/ Match	\$355,300	
Other Public Funds	\$100,100	
Other Private Funds	\$13,500	
Subtotal Other Funds		\$634,500
Total Program Funding		<b>\$1,572,000</b>

**Table 2**  
**I-15 National Test Bed, Phase 3**  
**Research Program Budget Cost Summary**

<b>Job Number</b>	<b>Job Description</b>	<b>FHWA TEA-21</b>	<b>State TEA-21</b>	<b>State Other</b>	<b>SPR W/ Match</b>	<b>Pooled Fund</b>	<b>Other Public</b>	<b>Other Private</b>	<b>Total Budget</b>
81F15301	Column-To-Bent Shear Tests, Phase 2	\$216,445	\$54,111		\$2,644				\$273,200
81F15302	Dynamic Characteristics of New Bridges	\$87,200	\$21,800		\$70,000				\$179,000
81F15303	Long-Term Eval. of Post-Ten. Spliced Girders (1 <sup>st</sup> Year)	\$104,000	\$26,000		\$59,000				\$189,000
81F15304	Computer Model and LRFD Design for Curved Steel Girder Br.	\$69,608	\$17,402		\$4,590				\$91,600
81F15305	Strong Motion Instrumentation. of Bridge Sites	\$79,588	\$19,897		\$35,715				\$135,200
81F15306	Long-Term Evaluation of FRP for Bridge Retrofit (1 <sup>st</sup> Year)	\$80,000	\$20,000		\$1,000		\$75,000 (Note 2)		\$176,000
81F15307	Ult. & Residual Capacity of Geopier Foundations	\$80,000	\$20,000		\$15,800			\$13,500 (Note 3)	\$129,300
81F15308	Long-Term Eval. Of MSE Walls on Soft Foundations	\$0	\$0	\$150,600 (Note 4)	\$75,300 (Note 5)		\$25,100 (Note 1)		\$251,000
81F15309	Corrosion Evaluation of Original I-15 Steel Pipe Piles	\$0	\$0		\$43,600				\$43,600
81F15310	Full-Scale Lateral Pile Cap and Backfill Load Testing	\$33,159	\$8,290		\$47,651				\$89,100
—	I-15 Test Bed Phase 3 Program Development			\$15,000 (Note 4)					\$15,000
	<b>Totals</b>	<b>\$750,000</b>	<b>\$187,500</b>	<b>\$165,600</b>	<b>\$355,300</b>	<b>\$0</b>	<b>\$100,100</b>	<b>\$13,500</b>	<b>\$1,572,000</b>

## Notes for Table 2

Note 1: Contingency from Phase 2, I-15 National Test Bed program funding.

Note 2: FY 1999 Innovative Bridge Research and Construction funding.

Note 3: Geopier Foundation Company.

Note 4: Utah State Transportation Construction Funds.

Note 5: FY 2003 Federal "State Planning and Research" funding.

The funding for Phase 3 would be allocated to each research study as shown in Table 2. A more detailed budget cost estimate is given at the end of each of the research work plans given herein. The costs shown include those incurred by the Department in managing and coordinating each research activity, which is estimated to be about 4% of the study cost. In addition, a 10% contingency was added to those studies that require field work on the I-15 corridor. Past experience has shown that this field contingency is a necessary part of interfacing with the design/build construction project, which can introduce many impacts to cost and schedule that are unknown at this time.

Also included is the cost of insurance (approximately 1%) incurred under the new *Owner Controlled Insurance Program* (OCIP). This program was first instituted as a cost saving measure on the I-15 Reconstruction Project. In the first year it had been shown to be so successful that an OCIP was developed for all Utah State government funded construction activities, including all of UDOT contracts. As a result, agency insurance costs are now required to be tracked on a project basis.

Note that the first six studies listed in Table 2 are related to the structural aspects of bridges while the next four are related to foundation aspects. Technology transfer activities will be undertaken by UDOT staff in conjunction with each project. Also note that the development of this Phase 3 program (last item listed in Table 2) was performed using State funds.

Funding for all of the projects listed in Table 2 (even those with multiple year scopes) represent one year's activities.

The SPR match shown in Table 2 is committed from the 2001 fiscal year, except in the case of Job Number 81F15308, where the SPR funds are committed from the 2003 fiscal year. Additional funding for Job Number 81F15308 was provide from State Funds, and the contingency included in I-15, Phase 2, because critical field activities had to be performed ahead of the Phase 3 program approval. This calculated risk was justified because of the unique opportunities that these studies represent and the critical nature of the I-15 reconstruction project schedule.

## Management of Research Studies

In accordance with federal regulations, the UDOT Research Division has developed and implemented a management plan (Report No. UT-95.10) for its research, development and technology transfer programs. The customers of UDOT's Research Division are primarily the end users of the research findings, both inside and outside of the Department. To provide the greatest possible service to these customers as well as to achieve most value for the research investment made, the Research Division staff performs several managerial functions on all research projects (over \$10,000) that it funds. These tasks include:

- Develop research contract documents and monitor technical & fiscal progress;
- Organize technical advisory committees (TAC);
- Assist principal investigator in development of technical working plans;
- Facilitate meetings between the TAC, the D/B contractor and the research teams
- Coordinate field activities with the D/B contractor and with other researchers;
- Process contract deliverables for review;
- Distribute published findings; and,
- Perform long term technology transfer activities.

As mentioned earlier, to improve the contracting process, the Research Division has taken over the function of developing research contracts from other divisions in the Department. This was necessary in order to be more responsive to the design/build reconstruction project schedule and to maintain controls over coordination with the D/B contractor as well as on cost and schedule.

The technical direction of the study and the competency of the findings are monitored by technical advisory committees (TAC). Committee members are chosen carefully to get a balance between researcher and end user perspectives. Sometimes out-of-state technical experts are invited to participate in special areas of interest. The TAC reviews the initial work plan and offers guidance throughout the study. The Research Project Manager facilitates meetings of the TAC and coordinates the review process.

Research contracts are generally written on a lump sum basis. Cost overruns are not allowed unless a change in scope is authorized. This requires the development of a detailed work plan, staffing plan, schedule and budget for the study, which must be agreed upon up front. Payment is made based on a list of deliverables. Research Project Managers assist the principal investigators in development of this work plan, which then becomes part of the contract documents.

One of the key functions performed by UDOT's Research Project Managers is coordination with the D/B contractor. This starts with identifying potential sites on the I-15 corridor that could be useful in performing research tasks already identified. The next challenge lies in determining schedule feasibility. All this must occur before research contracts can be finalized. Research Project Managers also are required to perform liaison between the research team and the D/B contractor in order to minimize point-of-responsibility conflicts. Opportunities for potential conflicts to arise are abundant once field work commences.

The responsibility of Research Project Managers for their project does not end when all the contract deliverables are submitted and the contract is closed out. They are responsible for publishing and distributing the UDOT final report, and are charged with continuing to perform technology transfer activities for up to two years after the work is complete, or until implementation is achieved. Thus, they become the primary steward to help assure that investments in research eventually pay off.

# Work Plans

## 81F15301 - Column-to-Bent Shear Tests

Funding Source:	FHWA Research (TEA-21 FY 2000)	\$ 216,445
	State Match (TEA-21 FY 2000)	\$ 54,111
	FY 2001 SPR incl. State match	<u>\$ 2,644</u>
	*Total Cost Estimate	\$ 273,200
Principal Investigator:	Fernando S. Fonseca, Brigham Young University David W. Jensen, Brigham Young University	
Research Project Manager:	Sam Sherman / Dan Avila	
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.		

## PROBLEM DEFINITION

The deterioration of the infrastructure of our nation is reaching crisis proportions. In the last twenty years numerous articles in technical engineering journal as well as newspapers and magazines have discussed on a regular basis the deteriorated condition of our bridges. Estimations are that nearly one quarter million bridges are structurally deficient. Some deficiencies are due to changing operating conditions; however, the majority is due to corrosion of the reinforcement and consequent spalling of the concrete cover. As the concrete fails, the load transfer mechanism is weakened and the capacity of the system is compromised.

Bridges in Utah are especially prone to this deterioration. Many of the bridges that have been recently replace along the I-15 corridor through Salt Lake City are typical of the deteriorated condition of our infrastructure system. Although most existing I-15 corridor bridges through Salt Lake City have recently been replaced, there is a large number of highway bridges throughout Utah that have not and will not be replace even though they are experiencing significant deterioration. Clearly, the cost of replacing such a large number of deteriorated bridges is prohibitive.

In addition to their present deteriorated condition, many bridges in Utah do not have adequate seismic detailing. A significant number of highway bridges throughout Utah were constructed before 1970, and thus lack appropriate seismic detailing. Seismic rehabilitation techniques have been used so these bridges meet minimal seismic requirements and at the same time have their original exterior condition restored. Seismic upgrading of older bridges is necessary; however, bridges are subjected to more than just seismic forces. Many studies have implied that the shear capacity of bridges is restored to its original condition by enhancing the shear capacity of columns and cap beam-column joints through various seismic rehabilitation techniques. Although this may be correct, there has been no research showing that the capacity of the cantilevered bent haunches is restored as columns and cap beam-column joints are rehabilitated.

In fact, there has been no research to date showing that the capacity of these cantilevered bent haunches is compromised due to deterioration therefore needing rehabilitation.

## **OBJECTIVES**

The objectives of this study are:

- To quantify the shear capacity of column-to-bent connections of existing deteriorated bridge structures and
- To quantify the improvements in capacity of these sections which have been either retrofitted or strengthened using advanced composite materials.

These objectives will be met by testing eight cantilevered bent haunches: six existing and two new.

The benefits which will result from this testing include:

- The measured response of the systems tested will become benchmark to any predictions of load capacities of similar systems.
- The opportunity to test column-to-bent connections of existing deteriorated bridges structures will provide valuable information on the actual load capacity of these elements.
- Practicing engineers could then use the empirical results to calculate load capacity of steel-reinforced concrete bridges of similar conditions across the country.
- The development of proven methods to strengthen and retrofit column-to-bent connections with advanced composite wraps would add confidence in the use of this technique and lead to improved designs in future applications.
- The results of the testing program can be used when determining whether deteriorated structures actually need to be repaired, the extent of the needed repair, and what type of repair will be most effective.

## **MAJOR TASKS**

The activities planned are described below and a tentative schedule is presented in Figure 1.

- Conduct a thorough literature review of retrofitting techniques.
- Determine capacity of existing column-to-bent connection.
  - Obtain the structural drawings and the AASHTO edition that governed the design of the bridges.
  - Determine the capacity of the connections using the AASHTO outlined procedure.
- Design loading apparatus.
  - Design a loading apparatus according with required capacity to test the connections. The anticipated large load requires such an apparatus to be carefully designed and constructed.
  - Assemble structural drawing for the apparatus.



- Fabricate loading apparatus.
  - Fabricate the apparatus according with structural drawing.
  - Assemble the apparatus exclusively for testing the connections, and disassemble and scrap after testing is complete.
- Construct and cure two new column-to-bent connections.
  - Contractor will build two new column-to-bent connections. These connections will be constructed according with structural drawings obtained during task No. 1.
  - Cure the connections for 56 days prior to testing.
  - Install the strain gages on reinforcement steel at critical locations.
- Transport the specimens from the storage to the structural laboratory.
- Prepare specimens for testing.
  - Cut the ends of the existing connections prior to testing.
  - During removal of the connections from existing bents, make cuts to provide a weak point for breakage of the bents.
  - Trim the specimens to fit within the loading apparatus.
- Set up instrumentation and data acquisition system.
  - Attach loading jacks and LVDTs to specimens and loading apparatus.
  - Make connections to the computer system.
- Conduct tests. Conduct monotonic tests according to the test matrix.
- Retrofit specimens accordingly and retest.
  - Retrofit and retest the specimens selected for retest.
  - Reinstall instrumentation and data acquisition.
- Dispose of specimens and loading apparatus.
  - Break specimens into pieces and dispose of accordingly.
  - Disassemble and scrap loading apparatus.
- Write report. Compile a report summarizing the testing procedure, results, and conclusions.

The experimental program associated with the tasks listed above, are as follows:

Shear-Joint tests will be conducted in a RETROFITTED and STRENGTHENED (RETRO) and an AS IS conditions to evaluate the capacity of bridge structures. A total of eight column-to-bent connections will be tested.

- Joints No. 1 and 2 are new construction (same reinforcement detail as existing joints) while joints No. 3 through 8 are from existing bridge bents.
- Joint Nos. 1 and 3 will be tested to failure and will serve as benchmark.
- Joint Nos. 2 and 4 will be tested to their yield capacities and then retrofitted using “conventional” wrapping.

These tests will provide information about loss or gain in strength due to the passage of time and will represent conditions of a pre-damaged specimen and the benefits of a retrofitting scheme.

- Joints No. 5 and 6 will be strengthened using the same retrofitting technique applied to joints No. 3 and 4.

- Joints No. 7 and 8 will be strengthened using a different technique than that of joints No. 5 and 6.

Tests conducted on joints No. 5 through 8 will quantify the improvements in capacity due to strengthening as compared to retrofitting schemes.

A summary of the planned tests is shown below in a test matrix:

Test No.	Construction	SHEAR-JOINT TESTS	
		AS IS	RETRO
1	New	Tested to Failure	No
2		Tested to Yield	Yes (1)
3	Old	Tested to Failure	No
4		Tested to Yield	Yes (1)
5	Old	No	Yes (1)
6		No	Yes
7	Old	No	Yes (2)
8		No	Yes (2)

(1) “Conventional” Wrapping, (2) Externally Bonded Panels or Chip, Epoxy and Patch Repair

## DELIVERABLES

The primary deliverable anticipated from this study will be a Final Report outlining the testing, data, results and conclusions. It will be submitted in both Draft and Final versions.

## STAFFING PLAN

This project will be under the direction of Dr. Fernando S. Fonseca, an Assistant Professor at BYU. Dr. David W. Jensen, an Associate Professor, will serve as the Co-Principal Investigator. Graduate students will be employed as needed to accomplish the stated research objectives. Various subcontractors will be employed for the construction of loading pads, transporting specimens, and retrofitting specimens.

## SCHEDULE

Activity	Mar '01	Apr '01	May '01	Jun '01	Jul '01	Aug '01	Sep '01	Oct '01	Nov '01	Dec '01	Jan '02	Feb '02
Design Loading Apparatus												
Fabrication of Loading Apparatus												
Construct and Cure New Bents												
Transport Specimens												
Prepare Specimens for Testing												
Set up Instrumentation												
Conduct Testing												
Retrofit Specimens and Retest												
Dispose of Specimens												
Write Report												

**Figure 1 - Schedule of Activities Starting March 2001**

## BUDGET SUMMARY

### BYU Contract Costs:

Personnel Direct Costs:	\$ 81,700
Equipment, Materials & Other Costs:	\$ 97,300
Subcontracts:	\$ 67,000
<i>Subtotal Contract Direct Costs, Equipment Etc. &amp; Subcontracts:</i>	<i>\$ 246,000</i>
<i>Indirect BYU Contract Costs:</i>	<i>\$ 24,600</i>
<i>Subtotal BYU Contract Costs:</i>	<i>\$ 270,600</i>

### UDOT Direct Costs:

Personnel Direct Costs:	\$ 0
Equipment, Materials & Other Costs:	\$ 2,600
<i>Subtotal UDOT Direct Costs, Equipment Etc.:</i>	<i>\$ 2,600</i>

**Total Project Costs:** **\$ 273,200**



## 81F15302 - Dynamic Characteristics of New Bridges

Funding Source:	FHWA Research (TEA-21 FY 2000)	\$ 87,200
	State Match (TEA-21 FY 2000)	\$ 21,800
	FY 2001 SPR incl. State match	<u>\$ 70,000</u>
	*Total Cost Estimate	\$ 179,000
Principal Investigator:	Marvin W. Halling, Utah State University Kevin C. Womack, Utah State University	
Research Project Manager:	Sam Sherman / Blaine Leonard	
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.		

### PROBLEM DEFINITION

The dynamic characterization of a structure prior to an earthquake is rarely if ever available. Therefore, it is difficult to compare and evaluate the dynamic properties of a structure before and after an earthquake. This type of information would be especially valuable because of the high seismic activity in Utah.

A unique feature of this study will be to utilize the installed strong motion instruments on a new structure to collect the data used in determining the dynamic properties of the structure. This will be valuable because it will significantly reduce the variables in the analysis when considering the structure in its “before,” “during,” and “after” states.

These strong motion instruments are some of the first to be applied to bridge structures within the state of Utah, and represent a significant start to the strong motion instrumentation program for the state.

The current researchers have performed several previous studies with very promising results and feel that by focusing on relatively simple structures where high quality and precise modeling can be performed in conjunction with the field testing, that the changes in the dynamic properties will be detectable and distinguishable.

In past work, a 20 kip eccentric mass shaker has been used to excite bridge structures. This shaker will also be utilized in this study. Additionally, bents will be excited using a modal hammer capable of generating a 5 kip impulse. The structural responses measured using the two excitation methods will be compared to determine if a significant portion of the response spectrum can be measured using simple modal testing equipment.

## **OBJECTIVES**

The objectives of this work are to:

- Using an eccentric mass shaker and both the newly to be installed strong motion instrumentation as well as additional accelerometers and seismometers, evaluate the dynamic properties of several new bridge structures to secure an adequate characterization of these bridges; and,
- Gather information to be used to compare the design models with the actual field data to see if the bridges behave as modeled.

## **MAJOR TASKS**

Among the bridges to be tested would be those that have permanent strong motion instrumentation installed, those that have free field instrumentation installed nearby, and those that are of particular structural or geotechnical significance. In the structures with permanent instrumentation, data obtained from the permanent instrumentation and from the additional temporarily placed instrumentation would be recorded, analyzed, and archived. For sites with no permanent strong motion instrumentation, the temporarily placed instrumentation would include free field instruments. In addition to the field testing, significant data analysis, modeling, and comparisons will be performed.

This testing would:

- Compare the structural behavior of these structures with the design assumptions;
- Be repeated every few years to evaluate the changes in the structures with time; and,
- Be repeated after a seismic event to evaluate the post-earthquake characteristics of these structures.

The properties of the structures are expected to change considerably with the first few years after construction. Therefore, it is proposed to repeat this testing in the future at approximately 2 years, 5 years, and every 5 years after that. This information would be of great interest to FHWA, UDOT, and many other state DOT's.

The structures will be instrumented with the strong motion sensors (accelerometers) and with velocity transducers (seismometers) will be vibrated utilizing the eccentric mass shaking machine. These structures will most likely be in the 106<sup>th</sup> South to 53<sup>rd</sup> South area and will be tested as the bridges are completed but before they are opened for traffic.

The schedule is still very tentative, but the researchers anticipate doing and archiving the results for up to 6 of the new structures in this area. The records from all the channels will be collected and analyzed to determine the “before” dynamic signatures of the structures. This information will then be archived so it can be of value in the future to compare the response of the bridge in a new condition to that of an older bridge. This will be valuable as a health monitoring tool when the condition of the bridge begins to decay, as well as a tool for the detection of damage that may occur from a future earthquake.

In the event of the future earthquake, the “before” and “after” data would be available for all the structures tested. The bridge structure selected for instrumentation will also be vibrated and will give additional data. This particular structure will not only provide “before” and “after” data, but will also provide “during” data in the event of a triggering earthquake. In addition, all of the installed channels will be used to characterize the structure during the forced vibration testing. Therefore, the exact same instruments will be used to record the structural motions before, during and after a seismic event.

The detailed steps are as follows:

- a. Locate and mount shaking machine on the structure;
- b. Use the installed instrumentation as well as additional instrumentation at many locations on the structure to gather data;
- c. Perform a full suite of frequency sweep testing of the structure;
- d. Data analysis and synthesis; and,
- e. Document and archive the data for future retrieval.

## **DELIVERABLES**

The dynamic behavior of these new bridges under forced vibration will be recorded, archived and maintained. This information will be placed on CD's for permanent storage. A CD is an ideal storage medium given the amount of data that will be collected and the permanent nature, given proper care, of a CD.

The recorded responses of the bridges will be analyzed to determine natural frequencies, mode shapes, and damping of each individual bridge. This information will be stored and utilized for comparison to subsequent forced vibration (or ambient vibration) tests conducted in the future, after a bridge (or bridges) have been subjected to deterioration or to a seismic event.

In the short term, the dynamic characteristics of these new bridges as determined by forced vibration testing will be compared to those used by the design engineers in their computer modeling and analysis conducted during the design phase of the project. Assumptions on damping and computer results with respect to natural frequencies and mode shapes can be compared to the actual characteristics of the structures. This will be a very strong indicator of the effectiveness of current structural modeling techniques and perhaps provide some insights into how to improve the modeling if there are discrepancies between the computer models and the as-built structures.

## **STAFFING PLAN**

The principal investigator for this project will be Dr. Marvin W. Halling, of the Utah State University Civil and Environmental Engineering Department. Dr. Halling has a strong background in earthquake engineering, geophysics, and vibrational testing of structures. His past research includes studies of the near source effects on base-isolated structures and includes

considerable work in processing and analyzing strong motion data. He has also installed instrumentation and performed vibrational testing on other I-15 structures. Dr. Halling will consult with and be assisted by Dr. James A. Bay, also of Utah State University. Dr. Bay has many years of experience in the characterization of the dynamic properties of materials, soils, and pavements. Dr. Bay's field experience is extensive and his knowledge in instrumentation and data processing is a great asset to the research team.

The in-field experimental work will be conducted by Dr. Halling, with assistance from Mr. Ken Jewkes, department technician/machinist, and several students from the civil and environmental engineering department at Utah State University. These students are: Mr. Kai Hseih (Ph.D. candidate) and several masters students. The data analysis will be primarily conducted by the masters students under the supervision of Dr. Halling.

The preparation of the final reports, journal articles and presentations will be by Drs. Halling, Bay, and the graduate students.

## **SCHEDULE**

The testing of bridges would commence as soon as the selected bridges are completed. Probably the best time to perform this testing is before traffic is on the structures, but it could also be performed after traffic is on the structures with some traffic control. The schedule will be dependant upon which structures are selected for testing.

## **BUDGET SUMMARY**

### **USU Contract Costs:**

Personnel Direct Costs:	\$ 108,000
Equipment, Materials & Other Costs:	<u>\$ 46,000</u>
<i>Subtotal Contract Direct Costs, Equipment Etc.:</i>	<i>\$ 154,000</i>
<i>Indirect USU Contract Costs:</i>	<u><i>\$ 15,400</i></u>
<i>Subtotal USU Contract Costs:</i>	<i>\$ 169,400</i>

### **UDOT Direct Costs:**

Personnel Direct Costs:	\$ 7,800
Equipment, Materials & Other Costs:	<u>\$ 1,800</u>
<i>Subtotal UDOT Direct Costs, Equipment Etc.:</i>	<i>\$ 9,600</i>

<b><i>Total Project Costs:</i></b>	<b><i>\$ 179,000</i></b>
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## **81F15303 - Long-term Structural Monitoring of Post-tensioned Spliced Girders and Deck Joints (First Year)**

Funding Source:	FHWA Research (TEA-21 FY 2000)	\$ 104,000
	State Match (TEA-21 FY 2000)	\$ 26,000
	FY 2001 SPR incl. State match	<u>\$ 59,000</u>
	*Total First Year Cost Estimate	\$ 189,000
Principal Investigator:	Chris P. Pantelides, University of Utah Lawrence D. Reaveley, University of Utah	
Research Project Manager:	Sam Musser / Stan Burns / Daniel Hsiao	
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.		

### **PROBLEM DEFINITION**

The purpose of the proposed project is to examine the long-term structural performance of the post-tensioned spliced concrete girders and the deck joints, currently being used in the construction of the new I-15 bridges. The study proposed here is for a long-term evaluation which is expected to last for five years. These relatively new girders have been used before in slightly modified form, however to the knowledge of the investigators, such a long-term health monitoring study has not been carried out for this type of girders. The effects of the permanent dead load, as well as the severe weather changes, the application of salt in the winter, and the freezing and thawing patterns in Utah make this an important study. The effects of this degradation on the creep and shrinkage characteristics of the girders and their influence on the overall structural properties of the bridge as a system are important in evaluating the long-term life of the newly constructed bridges, the design methods used, and the possibility of using these spliced girders in future projects.

### **OBJECTIVES**

- Collect data from instruments placed on two lines of spliced girders and the deck of an actual bridge on I-15. Currently, the Northbound 4500 South Bridge on I-15 is under consideration. The data shall be obtained using an automated data acquisition system which minimizes manual effort and gives more reliable data.
- Determine the material properties of the concrete, steel and tendons used for the girders.
- Compare the data obtained from the field with theoretical models using the AASHTO, PCI, and ACI Codes.

- Compare the data with established computer programs for vertical static load, dynamic load, thermal load, and losses.
- Develop guidelines for design modifications and improvements for the future design and application of these spliced girders. These guidelines will include recommendations such as curing time required before post-tensioning, improvement of connection details of the three girder segments, and joint movements in the deck.

## MAJOR TASKS

### 1. Concrete Material Properties:

Both short and long-term concrete material properties are of interest in this study. Knowledge of these properties will be crucial in the overall structural health monitoring evaluation. The short term properties to be determined:

- compressive strength of concrete as per ASTM C39;
- modulus of elasticity as per ASTM C469; and,
- coefficient of thermal expansion as per CRD C39.

The long-term properties of creep and shrinkage will be determined as per ASTM C512 at 3 days, 28 days, 90 days, 1 year and 2 years.

### 2. Long-term prestress losses:

Measure the long-term prestress losses of concrete post-tensioned spliced girders and the effect of these losses on strength and serviceability. Two girder lines of a bridge on I-15 will be instrumented with custom-made load cells, to observe the prestress losses from the time of tensioning to a period of five years. For this purpose two of the four tendons of each girder line will be instrumented with load cells at both the live and dead end. Currently, there are more than four methods which are used to estimate prestress losses, however none of the existing methods was developed based on this type of spliced girder. Moreover, the existing methods can differ by as much as 50% in their loss estimates.

### 3. Shear forces at the supports and splice points connecting the girders:

The spliced girders are made up of three segments. The two outer segments are equal and have a shorter length than the middle segment. It is of interest to correlate the shear transfer between the splice points of the three segments. This will be achieved by measuring the strains at adjacent sections using vibrating wire strain gages, between the three segments and at the supports.

### 4. Axial shortening of girders and the span:

It is important to be able to measure the axial shortening of the girders and the span resulting from the post-tensioning, and these measurements will be obtained from extensometers, LVDT's and vibrating wire strain gages.

### 5. Deflections and rotations of girders and girder segments:

The deflections and rotations of the individual girder segments as well as the whole girder will be obtained using the following methods: (a) using tiltmeters which are precise instruments and can measure directly the rotations and indirectly the deflections, (b) by conducting surveys of the bridge at regular intervals, and (c) by performing truck load tests using HS25 trucks once every year for five years. Comparisons with computer models shall be made.

6. Temperature Gradients:  
Thermal readings from the vibrating wire strain gages and external thermistors will be used to determine cross-sectional thermal gradients for both girders which will then be compared to AASHTO LRFD Specifications.
7. Frequencies and Periods of Girders and Bridge:  
The frequencies of the girders will be measured using oncoming traffic by employing accelerometers. These frequencies are an important parameter in determining the behavior of the bridge in future earthquakes. The experimental periods and mode shapes will be compared to structural models using the finite element method.

## **DELIVERABLES**

1. Instrumentation Report on installation details, equipment data sheets, equipment operation and daily field log;
2. First Year Data Report including experimental data and its interpretation, and subsequent reports for a period of five years;
3. Comparison of the experimental data with analytical computer models, theory, and design.
4. Development of guidelines for design modifications and improvements for the future design and application of spliced girders.

## **SCHEDULE**

The tasks for this project will be accomplished between December 2001 and December 2003.

## **BUDGET SUMMARY (First Year)**

### **UofU Contract Costs:**

Personnel Direct Costs:	\$ 52,000
Equipment, Materials & Other Costs:	\$ 69,900
Subcontracts:	<u>\$ 40,000</u>
<i>Subtotal Contract Direct Costs, Equipment Etc. &amp; Subcontracts:</i>	<i>\$ 161,900</i>
<i>Indirect UofU Contract Costs:</i>	<i><u>\$ 16,200</u></i>
<i>Subtotal UofU Contract Costs (First Year):</i>	<i>\$ 178,100</i>

### **UDOT Direct Costs:**

Personnel Direct Costs:	\$ 9,000
Equipment, Materials & Other Costs:	<u>\$ 1,900</u>
<i>Subtotal UDOT Direct Costs, Equipment Etc.:</i>	<i>\$ 10,900</i>

***Total Project Costs (First Year):*** ***\$ 189,000***

## **81F15304 - Computer Modeling and LRFD Design Equation Verification for Curved Steel Girder Bridges**

Funding Source:	FHWA Research (TEA-21 FY 2000)	\$ 69,608
	State Match (TEA-21 FY 2000)	\$ 17,402
	FY 2001 SPR incl. State match	<u>\$ 4,590</u>
	*Total Cost Estimate	\$ 91,600
Principal Investigator:	Kevin C. Womack, Utah State University Marvin W. Halling, Utah State University	
Research Project Manager:	Sam Sherman / Blaine Leonard	
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.		

### **PROBLEM DEFINITION**

The American Association of Highway and Transportation Officials (AASHTO) are beginning the process of developing design equations for the Load and Resistance Factor Design of curved steel bridge girders. To support this effort research engineers of the Federal Highway Administration, at the Turner-Fairbanks testing facility in McLean, Virginia, are testing full scale curved steel girders to develop data for the calibration of computer models and the verification of the AASHTO design equations. When these research engineers were informed that there is a three span, continuous curved steel girder bridge on the I-15 corridor which was to be demolished in late summer of 1999 they immediately expressed an interest in testing this bridge to provide additional data for the verification of computer models and design equations.

This work plan encompasses Phases II and III of a three phase project. Phase I was included in the I-15 Test Bed Phase 2 Program (81F15024, UDOT Report No. UT-99.04) and is near completion.

### **OBJECTIVES**

The main objectives of this research are to provide data on the response of an existing curved steel girder bridge, in three different condition states, when subjected to static and dynamic loads. And to calibrate, in combination with the data from the Turner-Fairbanks tests, a detailed and sophisticated computer model for curved steel girder bridges; and help verify, through the field testing and computer model, design equations developed for curved steel girders by AASHTO.

### **MAJOR TASKS**

The testing of the curved girder bridge at the I-15 and I-215 south interchange has been completed. The finite element models based on the static testing are near completion. Analysis

of the dynamic test data has begun and more finite element models based on both the static and dynamic testing results will be started in early 2000. The following are the tasks associated with both phases of this project, those completed in Phase I are indicated as such. Only the tasks associated with Phases II and III of the project are discussed in detail.

- Develop simple, preliminary computer models of the bridge (Phase 1 - complete);
- Collect data on the behavior of the bridge, in three condition states, when subjected to static and dynamic loads (Phase 1 - complete);
- Analyze the test data to determine the behavior of the bridge under static and dynamic loads (Phase 1 - partially completed);
- Develop a very detailed, sophisticated computer model for the analysis and prediction of behavior for cured steel girder bridges (Phase 2);
- Parameter study of the finite element model (Phase 2);
- Corroborate the computer model utilizing data from the I-15 field test and the Turner-Fairbanks testing (Phase 2);
- Verify the AASHTO equations for LRFD procedures to design curved steel girders (Phase 3); and,
- Produced a final report (Phase 3).

### Computer Modeling

Detailed finite element computer models for this bridge will be developed at both the FHWA and USU. These three-dimensional models will utilize both beam and shell elements with such detail that web and flange behavior for the steel girders will be well defined. It will be essential that the models be sufficiently detailed to determine precisely the strains at the points on the bridge where strain gages were placed during the field testing. The boundary conditions will also have to be precisely modeled based on data from the field testing.

### Parameter Study

The finite element model developed as part of this project will undergo a parameter study to determine how sensitive the model is to changes in structural characteristics, boundary conditions, friction between the slab and girders, etc.

### Corroborate Computer Model

The intent of the model developed based on the I-15 testing is to be able to model any type of curved steel girder bridge. If models of the bridge to be tested on I-15 and the girders being tested at Turner-Fairbanks are developed and confirmed by the test data to a point of high confidence, then these models can be altered to determine the characteristics of other curved steel girder bridges with different geometries, reducing the need for further laboratory and field testing.

## Verification of AASHTO Design Equations

Load and resistance factor design equations developed by AASHTO, potentially in part from the data collected on the I-15 and Turner-Fairbanks tests, will be verified by running a very large number of design scenarios on the computer models developed as part of this project. This will provide the level of confidence needed for AASHTO to seek approval for the curved steel girder design equations developed.

## Final Report

A final report based on the work performed by the USU researchers will be written. This report will contain important conclusions on the behavior of curved steel girders based on the results of the I-15 field testing. The results of the computer model developed for this bridge will be detailed and compared to the actual field testing data. In addition, sample design cases utilizing the AASHTO equations will be compared to computer models to show the behavior of a design based on the AASHTO equations.

## DELIVERABLES

The deliverables for Phases II and III of this project will be a detailed finite element model and calibration of these models based on the field test data. These models will be optimized and parameter studies examining the sensitivity of the model to changes in characteristics will be executed. This model will be used to corroborate AASHTO LRFD design equations. This comparison between design values and model output will be part of the information delivered as part of this research. A final report containing the above information will terminate the research.

## STAFFING PLAN

Kevin C. Womack, Ph.D., P.E., Principal Investigator

Marvin W. Halling, Ph.D., P.E., Co-Principal Investigator

This research project is a joint effort between researchers at the Federal Highway Administration (FHWA), led by Dr. Hamid Ghasemi, and the above researchers from Utah State University (USU). This work plan describes the research to be performed by researchers from both groups; however, the major focus will be on those efforts that are to be made by the USU researchers.

## SCHEDULE

The schedule for Phases II and III of the curved girder project (FY 00 funding) is shown in Figure 2. These phases are expected to stretch over the period of two years to accommodate the development of the AASHTO LRFD design equations.

Activity	Sep '00	Oct '00	Nov '00	Dec '00	Jan '01	Feb '01	Mar '01	Apr '01	May '01	Jun '01	Jul '01	Aug '01	Oct '01	Nov '01	Dec '01
Literature Search															
Computer Modeling															
Parameter Study															
Comparison of Analysis Method															
Final Report Preparation															

**Figure 2 Project Schedule – Computer Modeling and LRFD Design Equation Verification of a Curved Steel Girder Bridge, Phases II and III (FY00 funding)**

## BUDGET SUMMARY

### USU Contract Costs:

Personnel Direct Costs:	\$ 68,700
Equipment, Materials & Other Costs:	\$ 10,400
<i>Subtotal Contract Direct Costs, Equipment Etc.:</i>	<i>\$ 79,100</i>
<i>Indirect USU Contract Costs:</i>	<i>\$ 7,900</i>
<i>Subtotal USU Contract Costs:</i>	<i>\$ 87,000</i>

### UDOT Direct Costs:

Personnel Direct Costs:	\$ 3,700
Equipment, Materials & Other Costs:	\$ 900
<i>Subtotal UDOT Direct Costs, Equipment Etc.:</i>	<i>\$ 4,600</i>

***Total Project Costs:*** **\$ 91,600**



## 81F15305 - Strong Motion Instrumentation of I-15 Bridges

Funding Source:	FHWA Research (TEA-21 FY 2000)	\$ 79,588
	State Match (TEA-21 FY 2000)	\$ 19,897
	FY 2001 SPR incl. State Match	<u>\$ 35,715</u>
	*Total Cost Estimate	\$ 135,200
Principal Investigator:	Marvin W. Halling, Utah State University Walter J. Arabasz, University of Utah T. Leslie Youd, Brigham Young University	
Research Project Manager:	Steven Bartlett / Sam Sherman	
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.		

## PROBLEM DEFINITION

The worldwide database of strong motion records from moderate to large normal faulting earthquakes is extremely sparse. The Wasatch Fault ranks among the largest and most studied normal faults in the world, yet strong motion instrument coverage in the Salt Lake Valley is very inadequate, and elsewhere in the state is almost non-existent. The evaluation of seismic hazards for locations such as Salt Lake City, is often based on 'factors' applied to strong motion data obtained from strike slip or thrust events recorded elsewhere. The basin and range province, which encompasses much of Utah and Nevada, is an important extensional regime. If an earthquake occurred in Utah in the near future, not only would it be difficult to deal with losses, but very little information would be available about the ground motion which caused the damage.

For engineering applications, the extremely rapid information from strong motion instruments is not critical. However, the linking of systems and dense coverage by strong motion instruments is of benefit to all. Advanced systems are becoming prevalent in metropolitan areas that rely largely on the rapid gathering and distribution of information. The backbone of any advanced system is significant coverage of strong motion instruments. We propose that some, if not all of the instrumentation installed along the alignment of the I-15 will be utilized in the future advanced seismic systems for the Salt Lake City metropolitan area.

## OBJECTIVES

- To study the new alignment of the I-15 and develop a plan for the instrumentation of this alignment with strong motion instrumentation. It is anticipated that this instrumentation will consist of predominantly free field sites (3 channels installed at ground level) with a limited number of sites to include structural instrumentation (20 to 30 channels per structure), and/or down-hole instrumentation (6 to 9 channels).

- To purchase and install strong motion instruments at one structural site. This site will be of structural, geotechnical, and geophysical interest, and will include up to 30 channels, including 3 free field channels. This particular site will also include expandable data acquisition for the future installation of down-hole channels using future funding. The purchase of the instruments, data acquisition, and communication will be provided by this proposed work with the long-term annual maintenance costs being provided by UDOT Research or UDOT Structures possibly through a contract with the USGS. A cooperative effort is required to install, maintain, and manage data and data dissemination for this work, and should be seen as an initial investment with substantial future effort and funding in this area in future years.

## MAJOR TASKS

Coordination of the many interested parties is of the utmost importance for this research project. The researchers listed in this workplan will spearhead the study of possible instrumentation sites, but will certainly involve interested parties from UDOT, USGS, UGS, all three universities, and other government and private agencies. This study will result in a plan for the strong motion instrumentation for the I-15 corridor through the Salt Lake Valley and additionally will address the future direction of the strong motion “program” within the state of Utah.

Strong motion instrumentation will be purchased and installed on a new structure along the I-15 corridor which will be the first instrumented bridge structure in the state of Utah. This one site is to be the first of many sites to be instrumented in the state and represents a large step forward in working in conjunction with UDOT and other state groups such as the University of Utah Seismographic Station, and the Utah Geologic Survey. The site will consist of approximately thirty channels, including three “free field” channels which will be several hundred feet from the structure. The site which is yet to be determined.

In subsequent years, additional instrumentation will be placed at free field sites as well as on several additional interchange structures, and downhole sites. Ground motions generated by a moderate sized normal faulting event on the Wasatch Fault is of great interest both nationally and internationally since data recorded near a normal faulting event is very scarce. Additionally, obtaining a better idea of the effects of the soft clay soils in the Salt Lake Valley is of great local and national interest.

The detailed steps are as follows:

- a. Select an appropriate site based on geological and geotechnical site conditions, structural considerations, importance of structure, location with respect to future sites in the strong motion array
- b. Design the layout of the strong motion sensors based on structural models and drawings with consultation with experts with experience in instrumentation layout
- c. Purchase the system, which can be upgraded to be utilized as a near real time station in the complete array, and expandable to include the down-hole channels
- d. Install the system

The outcome of this part of the project is that there will be an instrumented site along the I-15 corridor which will be poised and ready to record any strong motion in the Salt Lake Valley. It is also significant because it represents the beginnings of a strong motion instrumentation program for the State of Utah.

## **DELIVERABLES**

- A plan for the instrumentation of the I-15 corridor through the Salt Lake Valley, also addressing strong motion instrumentation for the state of Utah.
- A functioning strong motion site on a new structure along the I-15.

## **STAFFING PLAN**

The Principal Investigators for this project will be Dr. Marvin W. Halling, of the Utah State University Department of Civil and Environmental Engineering. Dr. Halling will be assisted by various graduate students. The research team will coordinate with, and be assisted by UDOT engineers.

## **INTERESTED PARTIES**

A number of organizations and individuals are interested in this project. The following is a partial list of some of the interested parties. Certainly there are others.

Utah State University, Civil Engineering Department:

L. Anderson  
M. Halling  
K. Womack  
J. Bay  
J. Caliendo

University of Utah, Geophysics Department:

W. Arabasz  
J. Pechman

University of Utah, Civil Engineering Department:

L. Reaveley  
C. Pantelides

Brigham Young University, Civil Engineering Department:

L. Youd  
K. Rollins  
F. Fonseca

Utah Department of Transportation  
S. Bartlett, Research Division  
J. Bishoff, Geotechnical Division  
B. Wheeler, Structures Division

Utah Geological Survey  
G. Christensen

## **SCHEDULE**

Work on this project will require approximately one year to complete, with an anticipated beginning date of October 2000.

## **BUDGET SUMMARY**

### **USU Contract Costs:**

Personnel Direct Costs:	\$ 10,000
Equipment, Materials & Other Costs:	<u>\$ 81,600</u>
<i>Subtotal Contract Direct Costs, Equipment Etc.:</i>	<i>\$ 91,600</i>
<i>Indirect USU Contract Costs:</i>	<i><u>\$ 9,200</u></i>
<i>Subtotal USU Contract Costs:</i>	<i>\$ 100,800</i>

### **UDOT Direct Costs:**

Personnel Direct Costs:	\$ 8,000
Equipment, Materials & Other Costs:	<u>\$ 26,400</u>
<i>Subtotal UDOT Direct Costs, Equipment Etc.:</i>	<i>\$ 34,400</i>

<b><i>Total Project Costs:</i></b>	<b><i>\$ 135,200</i></b>
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### **81F15306 - Long-Term Durability of Carbon FRP Composites Applied to R/C Bridges (First Year)**

Funding Source:	FHWA Research (TEA-21 FY 2000)	\$ 80,000
	State Match (TEA-21 FY 2000)	\$ 20,000
	FY 2001 SPR incl. State match	\$ 1,000
	FY 1999 FHWA Innovative Br. R. & C.	<u>\$ 75,000</u>
	*Total First Year Cost Estimate	\$ 176,000
Principal Investigator:	Chris Pantelides, University of Utah Lawrence Reaveley, University of Utah	
Research Project Manager:	Sam Musser / Dan Avila / Daniel Hsiao	
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.		

### **PROBLEM DEFINITION**

Accelerated testing of Fiber Reinforced Polymer (FRP) composites has provided the small amount of information available today for durability of FRP composites. There is a real need for obtaining durability data for FRP composites from actual bridge applications. The State Street Bridge at Interstate 80 in Salt Lake City, was designed in 1965 according to the State of Utah Standard Specifications for Road and Bridge Construction, 1960 Edition and Supplements, and the AASHTO Specifications of 1961 and Interim Specifications. As such, the bridge was not designed to resist any earthquake-induced forces or displacements. The substructure consists of cast in place concrete piles, concrete pile caps, concrete columns and concrete cap beam. The girders are composite welded steel beams. The Principal Investigator has designed a seismic retrofit of the State Street Bridge using FRP composites, has participated in developing FRP composite specifications, and is involved in the implementation of the FRP composite design on the bridge; construction is scheduled to begin early in June of 2000. This is a unique opportunity to perform both destructive and non-destructive long-term durability studies of the FRP composite system. The engineering industry needs the information to be able to design, and specify composites for repair of the infrastructure with FRP composites. The unique characteristics of this bridge and Utah's weather can provide a natural test site.

The scope of this contract is limited to only one year's worth of data collection, testing and analysis. It is anticipated that subsequent contracts will be entered into to evaluate the performance over additional years.

## **OBJECTIVES**

The overall objective of the project is to study the in-situ degradation of strength and modulus of elasticity of carbon FRP composites, applied to a R/C concrete bridge. The severe weather changes, the application of salt in the winter, and the freezing and thawing patterns in Utah make this an important effort. In addition, a study of the effects of the FRP composite degradation on the overall structural properties of the bridge as a system shall be investigated. Specifically the following objectives will be achieved:

1. Evaluate the long-term reduction in strength and modulus of elasticity of the carbon FRP composite due to changes in temperature, alkalinity, chlorides, UV light and freezing and thawing cycles.
2. Evaluate the long-term effect of the FRP composite retrofit on the bond strength between FRP composite and concrete using mechanical and chemical testing.
3. Evaluate the long-term effect of the FRP composite retrofit on the strength and structural characteristics of the R/C bridge using strain gages.
4. Develop a reduction factor to be used in the design of FRP composites which incorporates the information gathered from the long-term monitoring of State Street Bridge.

## **MAJOR TASKS**

1. Measure the performance through the thickness of the FRP composite retrofit. The evaluation will consist of both specimens from the bridge and testing for isolated effects in the laboratory. This includes both the rectangular plates and NOL cylinder rings retrieved during construction.
2. Material property determination of reinforced concrete and FRP composite. Measurements will be obtained from both the columns and the beam cap of the FRP composite retrofit.
3. In-situ measurements of strains in the FRP composite using strain gages which are both embedded and on the surface of the FRP composite. In addition to ambient traffic, a truck load test will also be performed.
4. Installation of temperature and humidity sensors in the bents which are instrumented with strain gages, and synchronization of the readings through a date and time stamp. Installation of three displacement transducers to measure movement of the bent instrumented with strain gages.
5. Installation of an automated data acquisition and communication system. The automated data acquisition will enable quick and robust monitoring of strength degradation and changing characteristics of bridge retrofitted with FRP composites. The data acquisition will include a date and time stamp.

6. Installation of 15 FRP composite patches on the beam cap of the two State Street Bridge bents instrumented with strain gages. In addition, 15 more patches will be installed on the Highland Drive Bridge on the beam caps, where there is no carbon for comparison. These patches will consist of two layers of FRP composite taken from the production of that day and will be 16x16 in. in dimension. They will be attached to 14x14 in. HDPE plastic of ½ in. thickness, and affixed on the surface of the beam cap, where in the future they will be cut out. The patches will be removed at six month intervals in the first year to obtain specimens for tensile testing. After the first year, the patches will be removed at 12 month intervals. It is believed that these specimens will more closely reflect the actual condition of the CFRP composite.
7. Destructive testing of FRP composite tensile coupons and NOL rings at six-month intervals. These coupons will come out of FRP composite plates and cylinders which will be stored on the site, in steel boxes, which will be easily accessible.
8. Obtain cores of the concrete before application of the FRP composite to determine the chloride content of the concrete near the surface and inside the columns at the cover. In addition, obtain cores of the columns and the beam cap after they have been retrofitted with FRP composite to determine the bond between adhesive and composite, and between composite layers. The samples will consist of a core drilled sample of carbon fiber reinforced composite attached to concrete with an organic cement, on both at the State Street Bridge and the Highland Drive Bridge. The latter has an older FRP composite retrofit which has been in place since September of 1996. It has been observed that discoloration has occurred in certain areas facing the south, and cores will be taken both from the north and south faces. We will perform chemical analysis of the various components of the core drilled samples including:
  - Scanning electron microscopy (SEM) of the samples will be taken to visualize the microstructure of the concrete, organic cement and carbon fiber reinforced composite. Especial attention will be paid to the interfaces between layers. In addition, energy dispersive x-ray analysis (EDAX) of these images will be made to determine the high Z elemental analysis of the materials and interfaces. Comparison of the results from the aged samples with the fresh sample will give an indication of how the microstructure has changed with time and if the chemical makeup has been altered by the interaction of the sample with the interstate highway environment.
  - Low angle X-ray Diffraction (XRD) of the concrete at the interface with the organic cement will also be analyzed to see if there is a change in the crystal structure of this interface with time.
  - Thermal gravimetry (TG) and differential scanning calorimetry (DSC) will be performed on each of the individual organic components of the core samples to determine the glass transition temperature of the epoxy, the relevant phase transitions of the organic cement and the thermal decomposition of both the epoxy and the organic cement. With aging we expect that the epoxy and organic cement will become brittle which can be detected with a

decrease in the glass transition temperature and altered in its chemical makeup which can be detected with the finger print of the materials thermal decomposition.

- X-ray Fluorescence of the individual components of the core samples will be made to determine the elemental analysis of these materials. These results will be compared with the results from SEM-EDAX. This technique is more quantitative than EDAX and covers lower Z elements.
- Infra-red (IR) spectrometry will be performed on each of the individual organic components of the core samples to determine the types of chemical bonding found in the sample. An analysis of the differential spectrum, fresh minus aged, will allow the determination of the appearance of new bonds or the alteration of existing bonds in the sample. We expect the organic cement to undergo base hydrolysis leading to crosslinking and becoming more brittle with age. Furthermore, we expect that the epoxy will further cross link with Ultra-Violet exposure and undergo base hydrolysis with salt exposure and for both reasons become more brittle. Both of these processes will be detectable with IR analysis of the components. Additional microscope IR analysis will be performed at the interfaces of the organic cement with the concrete and the organic cement with the carbon reinforced epoxy composite. Here we will identify altered bonding due to the aging of the samples in the interstate highway environment.

With these various analyses we will be able to clearly identify the chemical changes that are taking place in the sample due to aging. We expect to use these chemical analyses in conjunction with the mechanical property testing done in this project to develop a chemical understanding for the degradation of mechanical properties of these carbon fiber bridge reinforcement materials. The purpose of these tests is to correlate the strength deterioration of the FRP composite and loss of bond to the chemical degradation.

9. Store 15 concrete blocks of dimension 6x12x4 in. with five-1 in. FRP composite strips for testing peel strength and bond of adhesive and FRP composite to concrete. At this time, it is anticipated that the test will be carried out using a modification of ASTM standard D1781, Standard test method for climbing drum peel for adhesives.
10. Comparison with predictive models of FRP composite confinement effectiveness. The defined specifications of the FRP composite will allow comparison of measured data to standard deviation of strength of FRP composite and reduction factors for design. Well defined design details of FRP composite for both strengthening and seismic retrofit will be verified with in-situ measurements.



## DELIVERABLES

1. Field installation of all instrumentation and test specimen collection and storage.
2. Instrumentation Report on installation details, equipment data sheets, equipment operation and field log.
3. Material testing of specimens.
4. First Year Data Report including experimental data and its interpretation, and subsequent reports, as funding allows, for a period of five years. This report shall include comparison of the experimental data gathered during the first year with analytical computer models and theory. Also included is development of guidelines for design reduction factors for durability of FRP composites applied to concrete bridges.

## STAFFING PLAN

The research team for the CONTRACTOR at the University of Utah will be as follows:

Principal Investigator	Chris Pantelides	Civil and Environmental Engineering
Co-Principal Investigator	Lawrence Reaveley	Civil and Environmental Engineering
Co-Principal Investigator	Terry Ring	Material Science

It is anticipated that 2 graduate students will participate in the project.

## SCHEDULE

The following schedule is anticipated under this contract. All work is to be completed and final products/deliverables are to be delivered to the UDOT Project Manager by June 30, 2002.

Activity	Mar '01	Apr '01	May '01	Jun '01	Jul '01	Aug '01	Sep '01	Oct '01	Nov '01	Dec '01	Jan '02	Feb '02	Mar '02	Apr '02	May '02	Jun '02
Instrument gages																
Instrument sensors																
Instrument data acquisition																
Instrument external																
Instrument report																
Materials Tests																
Analytical Models																
1 <sup>st</sup> FY Reports																

**Figure 3: Project Schedule - Long Term Durability of Carbon FRP Composite Applied to R/C Bridges (First Year)**

## **BUDGET SUMMARY (First Year)**

### **UofU Contract Costs:**

Personnel Direct Costs:	\$ 60,400
Equipment, Materials, Testing, & Other Costs:	\$ 93,600
Subcontracts:	<u>\$ 0</u>
<i>Subtotal Contract Direct Costs, Equipment Etc. &amp; Subcontracts:</i>	<i>\$ 154,000</i>
<i>Indirect UofU Contract Costs:</i>	<i><u>\$ 15,400</u></i>
<i>Subtotal UofU Contract Costs (First Year):</i>	<i>\$ 169,400</i>

### **UDOT Direct Costs:**

Personnel Direct Costs:	\$ 5,300
Equipment, Materials & Other Costs:	<u>\$ 1,300</u>
<i>Subtotal UDOT Direct Costs, Equipment Etc. &amp; Subcontracts:</i>	<i>\$ 6,600</i>

***Total Project Costs (First Year):*** ***\$ 176,000***

### **81F15307 - Ultimate and Residual Capacity of Geopier Foundations Subjected to Uplift and Compressive Loads**

Funding Source: FHWA Research (TEA-21 FY 2000)	\$ 80,000
State Match (TEA-21 FY 2000)	\$ 20,000
FY 2001 SPR incl. State match	\$ 15,800
Geopier Foundation Company (In kind)	<u>\$ 13,500</u>
*Total Cost Estimate	\$ 129,300
Principal Investigator:	Evert C. Lawton, University of Utah
Research Project Manager:	Steven Bartlett / Blaine Leonard
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.	

### **PROBLEM DEFINITION**

The performance of buildings and highway structures during an earthquake is critically dependent upon the ability of the foundation system to safely carry the compressive, uplift, and lateral loads generated by the earthquake. Owing to the high cost and logistical difficulty of conducting full-scale compressive, uplift, or lateral load tests on foundation systems to failure, only results from a few full-scale tests to failure are available in the open literature.

In previous testing at the I-15/South Temple site in Salt Lake City, Geopier foundation systems have been shown to be highly effective in resisting compressive, uplift, and lateral loads during simulated earthquakes. Geopier foundations were also shown to be highly ductile with the ability to sustain large deformations without failure. These attributes are beneficial in seismic areas where one of the main concerns is the ability of the superstructure and substructure to remain in service after an earthquake occurs.

Tests were also conducted in which isolated geopiers were failure in compression and uplift. Results from these tests showed that geopier foundations could be a viable and economical alternative to deep foundations in seismic areas in some cases. However, owing to a variety of circumstances, tests on full-scale foundations supported by groups of geopiers were not loaded to failure.

Thus the ultimate capacity and mechanisms of failure for geopier foundations are still not clearly defined. Fortunately, most of the infrastructure is currently in place to conduct tests at this site where full-scale geopier foundations can be loaded to failure from all three types of loads.

## **OBJECTIVES**

Perform full-scale tests in which geopier foundations are loaded to their ultimate and residual capacities when subjected to compressive, uplift, and lateral loads.

Determine the mechanisms by which geopier foundations reach their ultimate and residual capacities.

Improve existing methods or develop new methods for the determination of ultimate and residual capacities of these foundations systems when subjected to compressive, lateral, and uplift forces.

## **MAJOR TASKS**

Characterization of the subsurface materials. This task is necessary to ensure that the foundation support systems are designed properly, the results from the full-scale field tests are interpreted correctly, and the numerical and theoretical analyses extending these results to other conditions are successful. A significant characterization of the subsurface materials at the site has already been accomplished in previous research. Some additional testing is needed specifically at the location of the two new foundations described below.

Install two new geopier foundations and reaction geopiers. An existing foundation 8'-3" wide by 24'-6" long supported by ten geopiers will remain after completion of the bent pushover tests this winter or spring. This foundation is located adjacent to three groups of piles and can be used for tests in which it is loaded laterally by reacting against an adjacent pile cap located to the west or a group of free-headed piles to the north. However, it is not suitable to load it to failure in compression or uplift primarily because of the tremendous capacity required for either mode (estimated to be about 2000 kips in ultimate compressive or uplift capacity). Therefore, two smaller foundations supported by four or five geopiers will be constructed for use in the compressive and uplift tests. Adjacent reaction geopiers are required to generate the force necessary to load these foundations to failure.

Install reaction geopiers and construct load frame to vary the vertical normal force acting on the existing geopier foundation. A cyclic lateral load test has already been conducted in which the geopier foundation was loaded close to its ultimate capacity under the weight of the footing itself (about 100 kips). One of the main mechanisms by which lateral resistance develops in a geopier foundation is from frictional sliding resistance along the footing-geopier interface. Therefore, to determine the lateral capacity of this geopier foundation, it will be necessary to vary the normal force. This can be accomplished by installing reaction geopiers on opposite sides of the footing, installing a horizontal reaction beam above the footing and tying it into the reaction geopiers, and jacking simultaneously against the top of the footing and the reaction beam. Because the footing will move laterally during these tests, it will also be necessary to develop a roller system to enable the footing to move laterally while the jack remains in place.

Conduct full-scale field tests. It is anticipated that the following full scale tests will be conducted:

- a. Lateral tests to failure on existing geopier footing. The lateral loads will be generated by pushing against an adjacent pile cap. Cyclic loads will be applied until ultimate and then residual capacities have been achieved in the geopier foundation (and in the pile cap). Tests will be conducted both with and without backfill. These tests will be conducted in conjunction with BYU (headed by Dr. Kyle Rollins). This footing is currently instrumented with pressure plates within the geopiers, push-in cells within the matrix soil, strain gages within the reinforcing steel and uplift geopier bars. Lateral and vertical displacements of the footing will be monitored with displacement transducers.
- b. Compressive tests to failure on a new geopier footing. This footing will be supported by four or five geopiers and will be loaded cyclically to ultimate compressive capacity by reacting against a horizontal reaction beam. Pressure plates, push-in cells, and strain gages will be installed within the geopiers and footings. Inclometers will be installed adjacent to the footing to monitor movements of the soil adjacent to the geopiers outside the footprint of the footing. Displacement transducers will be used to monitor vertical and lateral movements of the footings.
- c. Uplift tests to failure on a new geopier footing. This footing will be supported by four or five geopiers and will be loaded cyclically to ultimate uplift capacity by reacting against a horizontal reaction beam. Pressure plates, push-in cells, and strain gages will be installed within the geopiers and footings. Inclometers will be installed adjacent to the footing to monitor movements of the soil adjacent to the geopiers outside the footprint of the footing. Displacement transducers will be used to monitor vertical and lateral movements of the footings.
- d. Analyze data from the field tests. The results from the field tests will be determined by analyzing the data from the tests.
- e. Determine suitability of existing methods for estimate ultimate capacities, and if necessary, develop new methods. The results from the field tests will be compared with predictions from existing methods of analysis to determine if these methods provide realistic estimates of ultimate capacities. If not, new or modified methods will be developed.
- f. Produce a final report. A final report providing details, results, and conclusion from the research will be produced.

## DELIVERABLES

The following deliverables are anticipated:

1. Completion of the field work.
2. Analysis, design method, and Final Report.

## STAFFING PLAN

The Principal Investigator for this research project will be Dr. Evert C. Lawton, of the University of Utah Civil and Environmental Department. Dr. Lawton will be assisted by a team of graduate and undergraduate students. Installation of Geopier Foundations will be performed by a subcontractor.

## SCHEDULE

The schedule shown in Figure 4 is based on the assumptions that the site will be available to begin the research study on March 1, 2000 and that funding for this work will be available at the same time.

Activity	Mar '01	Apr '01	May '01	Jun '01	Jul '01	Aug '01	Sep '01	Oct '01	Nov '01	Dec '01	Jan '02	Feb '02
Subsurface exploration and testing												
Design and procure instrumentation												
Design geopiers and footings												
Install geopiers including buried instrumentation												
Construct and instrument two new footings												
Allow footings to cure												
Perform lateral tests on existing footing												
Perform uplift test on new footing												
Reduce and analyze data from field tests												
Analyze existing design/analysis methods, develop new if needed												
Prepare final report												

**Figure 4: Project Schedule - Ultimate and Residual Capacity of Geopier Foundations Subjected to Uplift and Compressive Loads**

## BUDGET SUMMARY

### UofU Contract Costs:

Personnel Direct Costs:	\$ 48,200
Equipment, Materials & Other Costs:	\$ 65,800
Subcontracts:	<u>\$ 12,000</u>
<i>Subtotal Contract Direct Costs, Equipment Etc. &amp; Subcontracts:</i>	<i>\$ 126,000</i>
<i>Less Geopier Foundation Company In-kind Match:</i>	<i>\$ 15,000</i>
<i>Net UofU Contract Direct Costs:</i>	<i><u>\$ 111,000</u></i>
<i>Indirect UofU Contract Costs:</i>	<i><u>\$ 11,300</u></i>
<i>Subtotal UofU Contract Costs:</i>	<i>\$ 122,300</i>

### UDOT Direct Costs:

Personnel Direct Costs:	\$ 5,900
Equipment, Materials & Other Costs:	<u>\$ 1,100</u>
<i>Subtotal UDOT Direct Costs, Equipment Etc.:</i>	<i>\$ 7,000</i>

***Total Project Costs:*** ***\$ 129,300***





## 81F15308 - Long-Term Evaluation of Mechanically Stabilized Earth Retaining Walls on Soft Foundations

Funding Source:	FHWA Research (TEA-21 FY 2000)	\$ 0
	State Match (TEA-21 FY 2000)	\$ 0
	FY 03 SPR Incl. State Match	\$ 75,000
	Utah State Transportation Construction Funds	\$ 150,600
	I-15 Test Bed Phase 2 Contingency	<u>\$ 25,100</u>
	*Total Cost Estimate	\$ 251,000
Principal Investigator:	James A. Bay, Utah State University Loren R. Anderson, Utah State University Joseph A. Caliendo, Utah State University	
Research Project Manager:	Steven Bartlett / Clifton Farnsworth	
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.		

### PROBLEM DEFINITION

The current construction project along the I-15 corridor makes extensive use of Mechanically Stabilized Earth (MSE) walls. Approximately, 160 MSE walls are planned for the project and about two-thirds of these walls have been constructed or are currently in intermediate phases of construction. Construction on the I-15 is complicated by presence of soft clays, which underlie much of the northern part of the project. Tall (8 m and greater) MSE walls will typically experience about 1 m of settlement near the face of the wall. These soft foundation conditions and high settlements pose challenges for design and construction of MSE walls. Most of the tall MSE walls on this project employ a two-stage construction, where the embankment and reinforcement is constructed during the first stage, after most of primary settlement is complete, precast concrete facing panels are placed on the wall during the second stage.

The wire faces of many currently constructed walls have exhibited large deformations. These deformations include bulging, sagging, and negative batter. The facial welded wire is often highly distressed with buckled and broken wires. It is not immediately evident if these conditions at the wall surface are associated with overstressing within the wall, or if the distress is limited to the face of the walls.

Because of the deformations in the walls constructed early in the project, the design of the later walls have been modified to include shorter, intermediate bar mats between the lower primary reinforcement mats.

This research is to instrument a section of wall R-346-1C to monitor the stresses and strains in wall and foundation soils through construction, primary consolidation, and secondary consolidation. Instrumentation will include, strain gages on the bar mats, pressure cells at the base of the fill, horizontal and vertical inclinometers in the foundation and fill, vertical

extensometers in the foundation, horizontal extensometers in the fill and survey monuments. Bar mats will be instrumented in two sections of the wall. One where the intermediate reinforcement is omitted and another section with the intermediate reinforcement. Horizontal extensometers will be included in both sections. The data from these two sections will provide a better understanding of how the intermediate reinforcement affects the stress and strain fields in wall.

During the design phase of I-15, an issue was raised about the quality of soil samples being obtained. Problems of sample disturbance and assessing the quality of soil samples complicated the geotechnical design of the I-15 reconstruction. Many soil specimens sampled using conventional shelly tubes were rejected as being too disturbed. Additional soil samples were obtained using piston samplers. The geotechnical consultant x-rayed all samples and did not reject nearly as many of the soil samples obtained using piston samplers. Although not known to what degree, the observation was that soil samples obtained using shelly tubes experience more disturbance than soil samples obtained using piston samplers.

The current state of practice for obtaining samples from the Bonneville Clays in the Salt Lake Valley is to use conventional shelly tubes. However, if shelly tube samples are too disturbed to obtain soil properties in the design process, and samples obtained using piston samplers are not, then the current state of practice needs to be addressed.

## **OBJECTIVES**

The major concept of this study is to do long term monitoring of an MSE wall for ten years. However, that concept is outside the scope of this contract. This contract only covers the first two years of the long term monitoring of an MSE wall. There are three major objectives to be achieved within the scope of this research project, as follows:

1. **MSE WALL MONITORING:** This research is to instrument a section of wall R-346-1C to monitor the stresses and strains in wall and foundation soils through construction, primary consolidation, and secondary consolidation. Instrumentation will include the following: strain gages on the bar mats, pressure cells at the base of the fill, horizontal and vertical inclinometers in the foundation and fill, vertical extensometers in the foundation, horizontal extensometers in the fill, and survey monuments. Bar mats will be instrumented in two sections of the wall. The first is where the intermediate reinforcement is omitted and the other section with the intermediate reinforcement. The data from these two sections will provide a better understanding of how the intermediate reinforcement affects the stress and strain fields in the wall.

The heavily instrumented sections of MSE wall R-345-1C will provide a valuable opportunity to assess the long-term performance and behavior of the MSE walls built during the I-15 Reconstruction. Repeated monitoring of the instruments will provide detailed information about movements in the wall and foundation, and any changes in stress conditions in the wall.

2. **LABORATORY INVESTIGATION ON SAMPLE DISTURBANCE:** This research is to obtain samples of the soft Bonneville clays near wall R-346-1C and perform a laboratory investigation on the sample disturbance and properties of these soils. An evaluation will be performed on the relative sample disturbance of soft Bonneville clays samples using shelly tubes and piston samplers. Sample disturbance will be determined from x-ray images of the sample

tubes, consolidation tests and undrained triaxial tests. The results of this work will establish guidelines for sampling soft Bonneville clays. The current state of practice in obtaining samples from the Bonneville clays is to use Shelby tubes. This research will evaluate whether piston samplers extract samples with a lesser degree of disturbance than samples obtained with Shelby tubes and to what degree of disturbance each method allows.

In addition to the investigation of soil sample disturbance, soil testing will be performed to determine the strength and deformation properties of soft Lake Bonneville deposits near the instrumented MSE wall. Constant rate of strain and incremental loading tests will be performed to make a careful determination of the soil preconsolidation stress and compressibility. Long-term creep tests will be performed to estimate the secondary compressibility of the soils. A series of  $K_0$  consolidated undrained triaxial tests will be performed to determine the SHANSEP parameters to predict the undrained shear strength of soft lake Bonneville deposits. These soil parameters will provide valuable tools for geotechnical designers on future projects on soft Bonneville clays.

3. ANALYTICAL MODELING OF MSE WALL: The detailed measurements of the stress and strain fields in and beneath a MSE wall, along with careful measurements of soil properties obtained from this work provides a unique opportunity to verify both the soil parameters measured in the laboratory and the model used to predict the wall behavior. The measured soil properties and wall geometry will be incorporated into a finite element, or finite difference analytical model. The behavior of the wall predicted in the model will be compared to the behavior measured in the instrumentation program. Any adjustments that must be made in the model or soil parameters to cause the predicted behavior to match the measured behavior will be noted. The soil parameters and the calibrated analytical model will provide valuable tools for geotechnical designers on future projects involving embankments on soft Bonneville clays.

## **MAJOR TASKS**

### **MSE WALL MONITORING**

Instrumentation will be installed on wall R-346-1C near 3300 South St. in Salt Lake City. This wall will be about 8 m high and about 450 m long. Construction is scheduled to begin on this wall in September 1999.

Figure 5 shows the general instrumentation plan for the wall. The instrumentation consists of vertical and horizontal inclinometers, vertical and horizontal extensometers, survey monuments, pressure plates, and Instrumented bar mats.

Before construction of the wall, one horizontal slope inclinometer casing will be installed on the foundation below the wall. Three vertical slope inclinometer casing will be imbedded in the wall foundation to a depth sufficient to penetrate the soft Bonneville and Cutler deposits. Three Sondex type vertical extensometers will be installed adjacent to the vertical inclinometer casings. Benchmark readings will be made in each inclinometer and extensometer before construction commences. During construction one additional horizontal slope inclinometer casing will be installed in the fill, and one of the vertical inclinometers with its associated vertical extensometer

will be extended through the fill. Fig. 6 shows the relative positions of the vertical and horizontal inclinometers and the vertical extensometers.

Horizontal extensometers will be installed in the fill during construction to monitor the displacements within the fill. These extensometers will consist of a plate embedded in the fill attached to an isolated rod extending through the face of the wall. Fig. 7 shows a drawing of a horizontal extensometer. A series of five extensometer plates will be embedded at distances of: 1, 2, 4, 8, and 16 ft from the face of the wall. Seven series of five inclinometers will be installed at intervals along the height of the wall at two sections of the wall. Fig. 7 shows how the horizontal extensometers will be positioned at the two sections of wall.

An array of survey monuments will be installed to measure deformations around the instrumented sections of wall and reference monuments, away from the wall will be established. The horizontal and vertical position of these monuments will be surveyed before construction commences.

Prior to construction, an array of five pressure plates will be installed on the foundation. Fig. 8 shows the configuration of the pressure plates.

Strain gages will be installed at intervals along the length bar mats and calibrated. Instrumented bar mats will be installed in three different regions of the wall. First, in a section of wall where the intermediate reinforcing has been omitted. A cross section of the wall showing position of instrumented bar mats in this section is shown in Fig. 9. A second section of wall, with intermediate reinforcing, will also receive instrumented bar mats as shown in Fig. 10. The third section of wall receiving instrumented bar mats will be the face of the wall.

Measurements of force in reinforcing elements and deformations in the wall and foundation will be made at regular intervals during construction and during post-construction settlement. Care will be taken to preserve access to the instrumentation throughout construction. Ports will be constructed in the precast concrete facing panels to allow access to the horizontal inclinometer casing and horizontal extensometers after the facing panels are installed. Measurements will continue at regular intervals as long as forces and deformations change and then at longer intervals for long term evaluation of the wall performance.

An installation report will be issued to UDOT at the end of the installation process. This report will include the overall project scope, objectives, and plan. A detail of the instrumentation contained in the wall, including instrumentation type, details, specifications, layouts, and wiring diagrams will also be included. Finally, the project description, construction conclusions, reading technique, and monitoring plan will also be included.

Post construction monitoring reports will be prepared at the end of each of two years, based on the measurements which will be made at regular intervals of at least once a quarter for long-term evaluation of the wall performance.

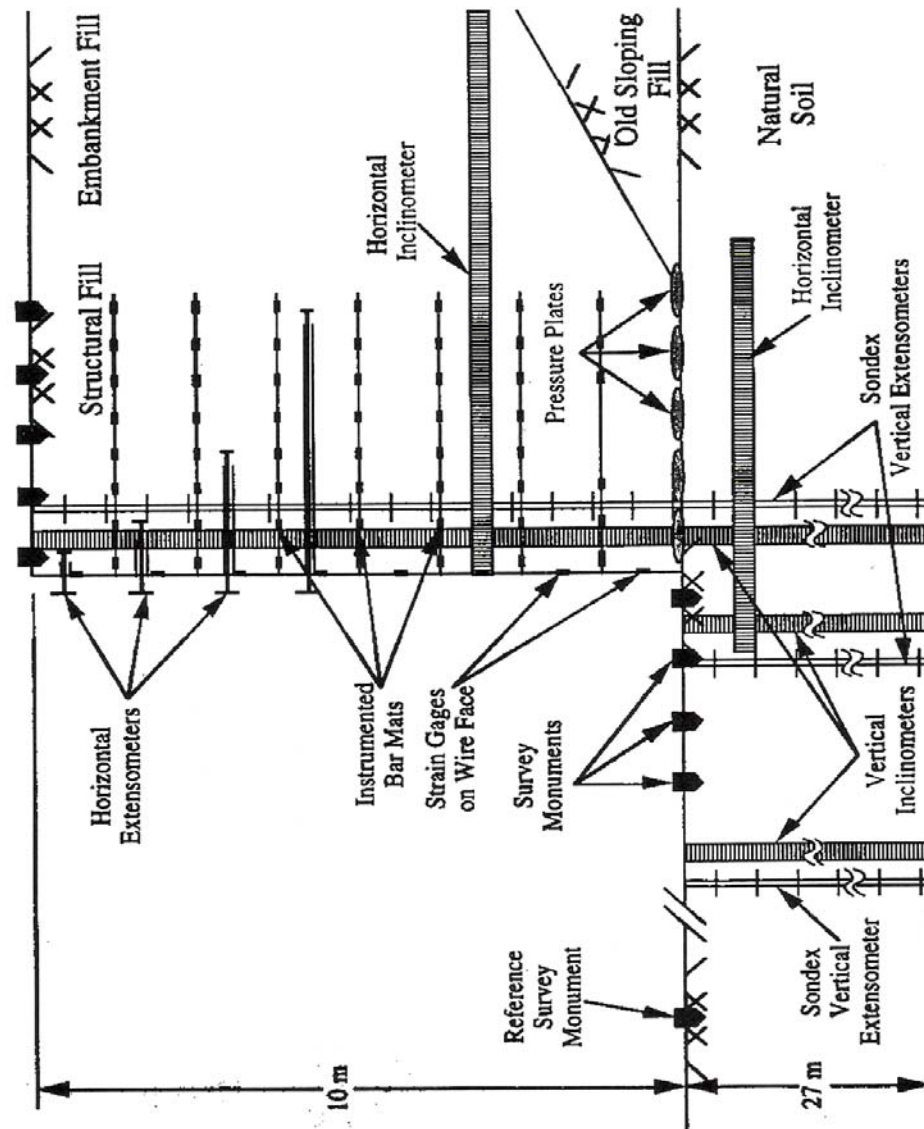
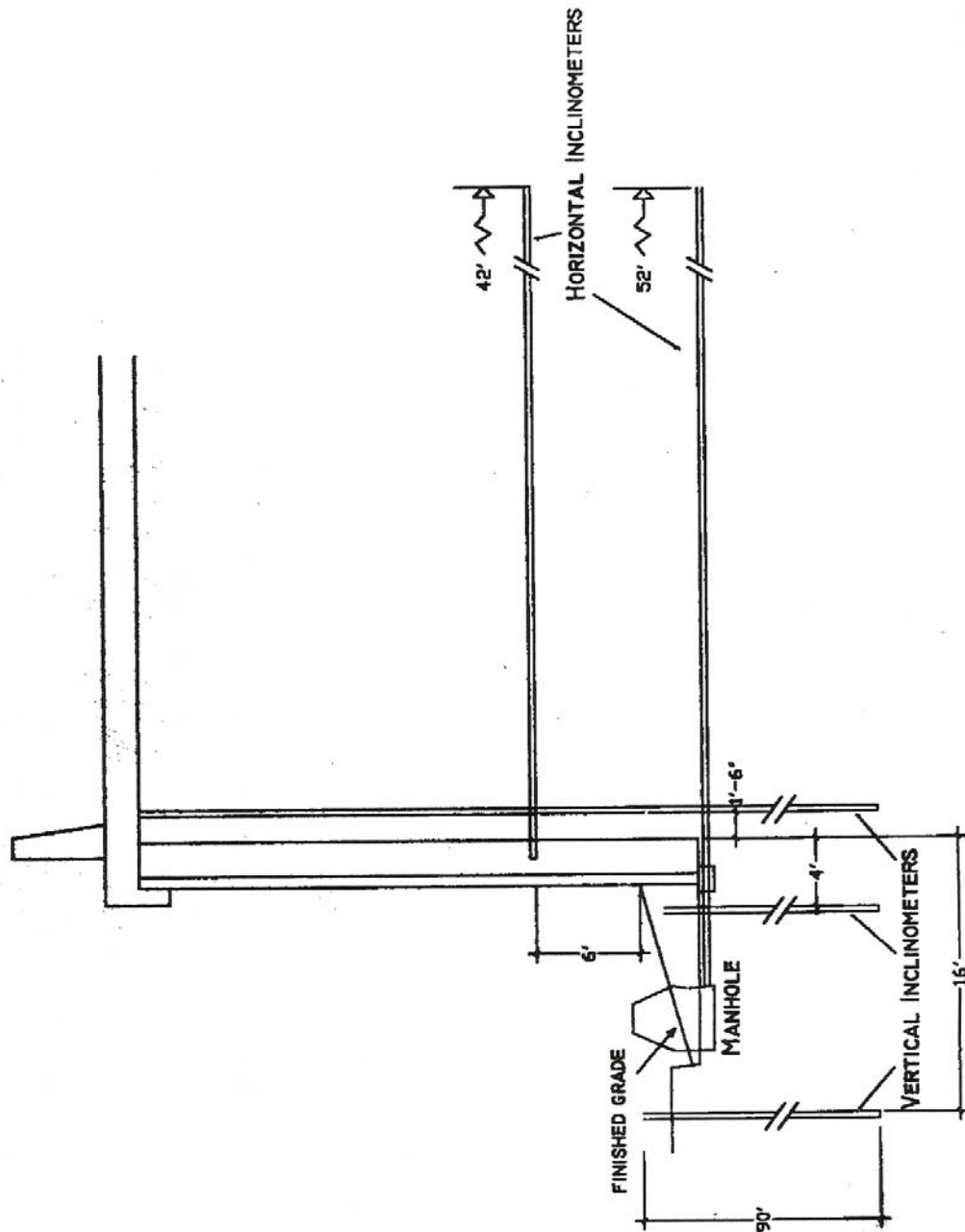


Figure 5 - General Instrumentation Plan for MSE Wall R-346-1C



**Figure 6 - Configuration of Horizontal and Vertical Inclinometers in Wall R-346-1C**

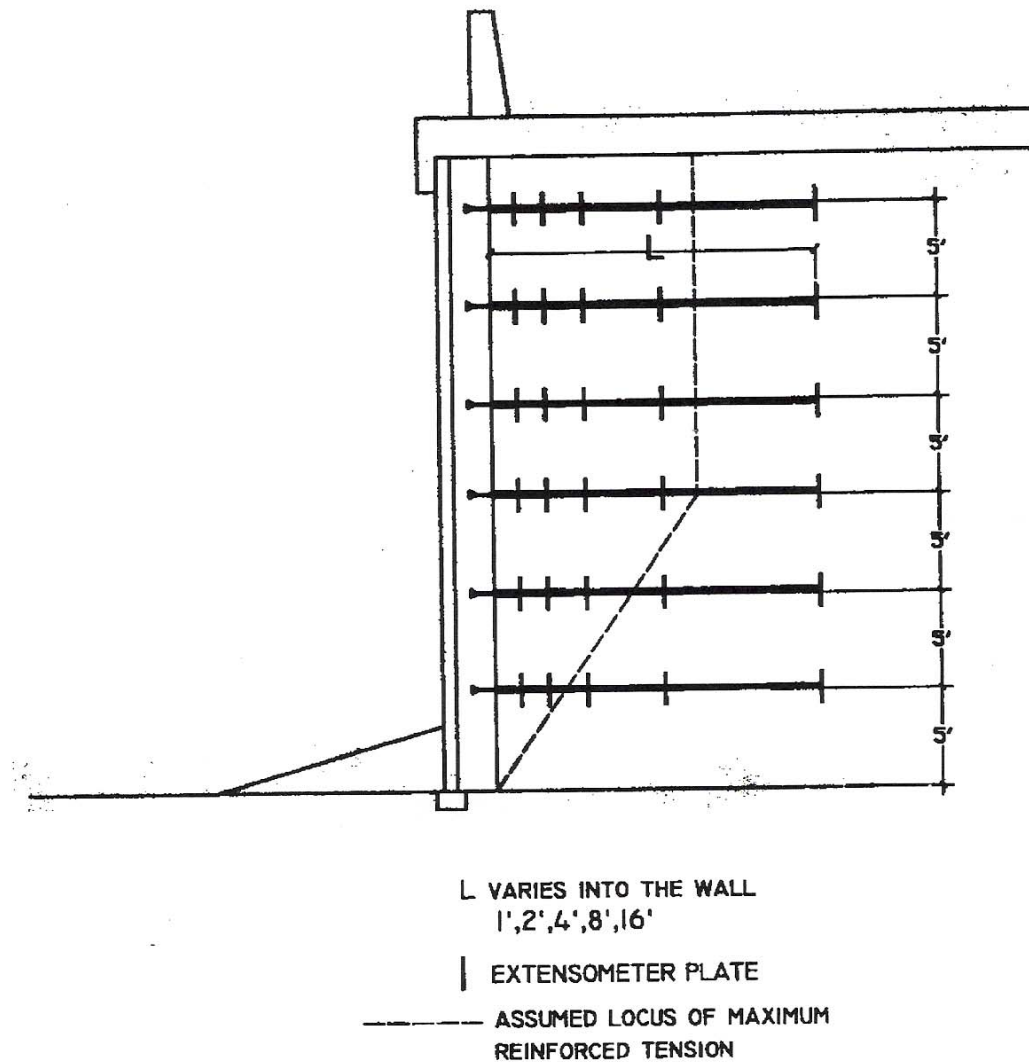
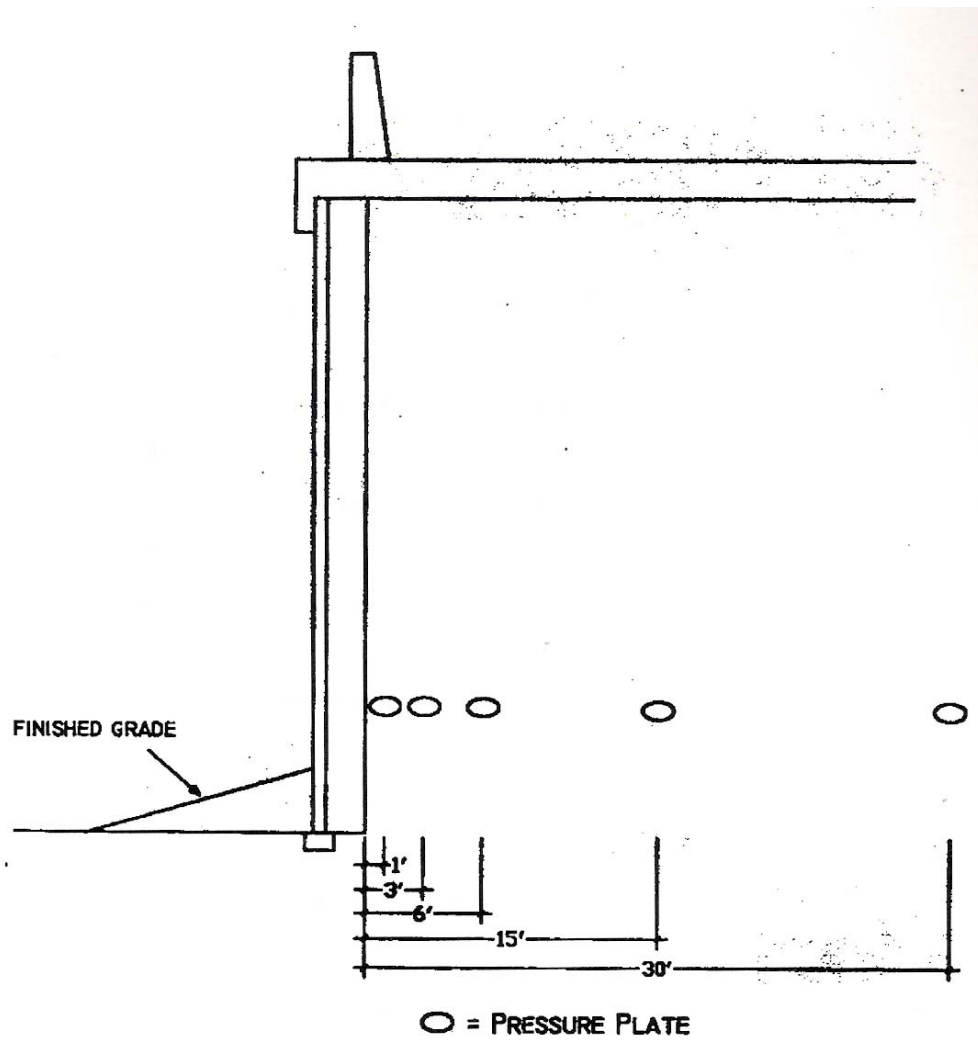


Figure 7 - Configuration of Horizontal Extensometers in Wall R-346-1C



**Figure 8 - Configuration of Pressure Plates in Wall R-346-1C**



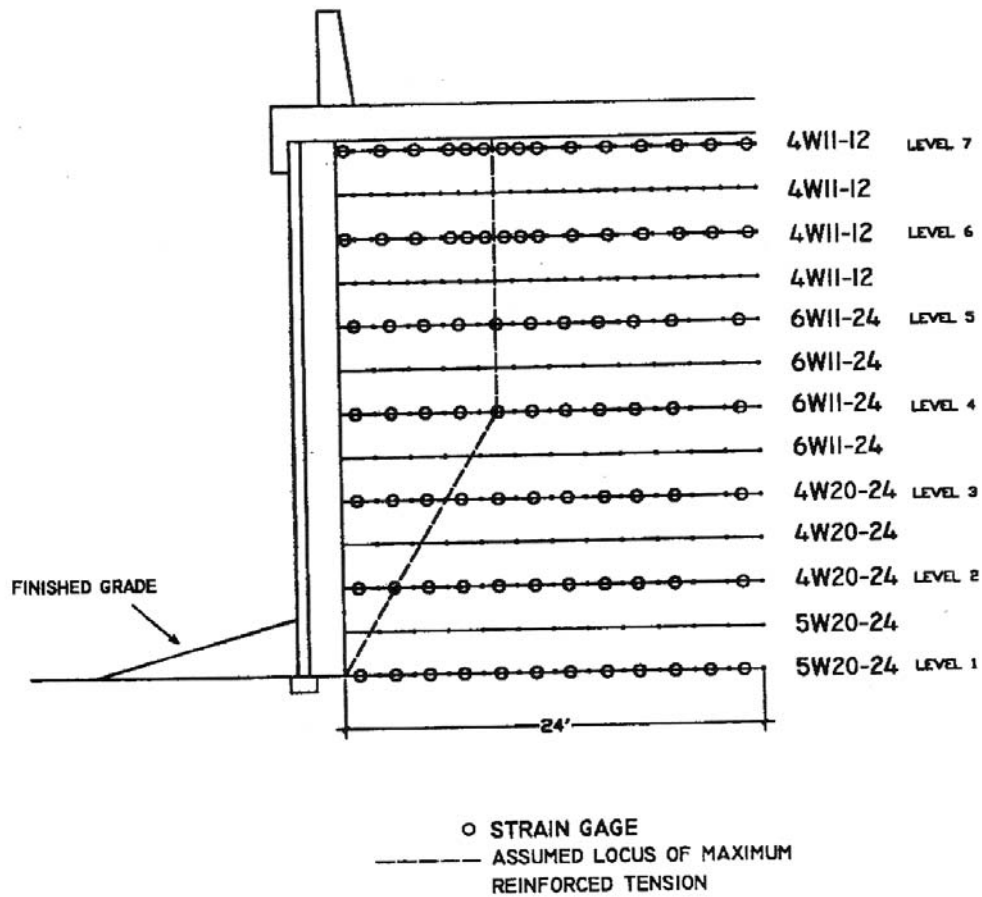
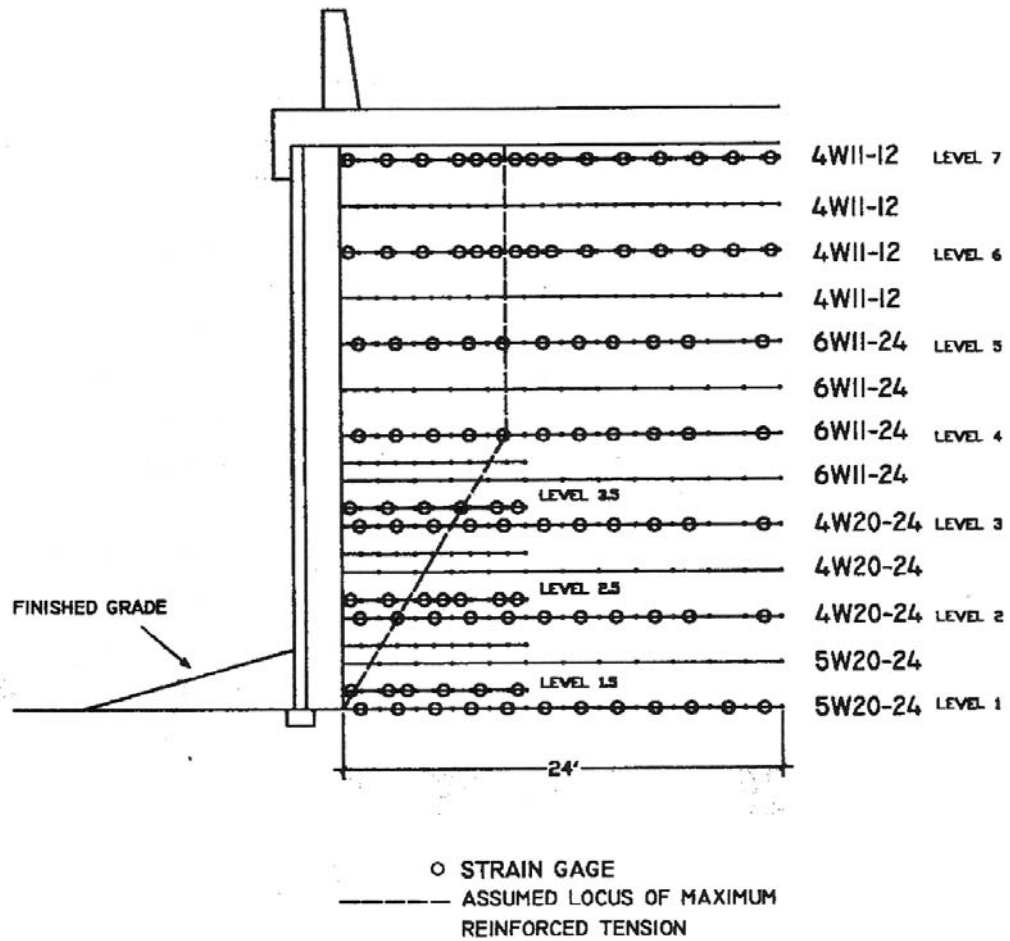


Figure 9 - Configuration of Strain Gages on Bar Mats in Section of Wall R-346-1C



**Figure 10 - Configuration of Strain Gages on Bar Mats in Section of Wall R-346-1C with Intermediate Reinforcement**

## LABORATORY INVESTIGATION OF SAMPLE DISTURBANCE

The piston and shelly tube samples obtained during the installation of the vertical inclinometer and extensometer will be analyzed for disturbance and used for consolidation testing. Additional drilling will also be carefully conducted near the MSE wall to obtain additional samples from the Bonneville clay layers using both the piston sampler and shelly tube sampling methods.

The shelly tube and piston samples obtained near the wall site will be X-rayed to assess relative sample disturbance and quality of sample obtained. Constant Rate of Strain and incremental loading tests will be performed to identify the soil preconsolidation stress and compressibility of the soil samples. A series of  $K_0$  consolidated undrained triaxial testing will be performed on these samples, in order to assess undrained and effective strength parameters, and the SHANSEP parameters for the soils. Secondary compressibility and reload compressibility will also be determined for both sets of samples using long-term creep tests.

The strength and deformation properties found for both the shelly tube and piston samples obtained near the MSE wall will be compared to each other. The final report will focus on relative sample disturbance and the quality of samples obtained in the Bonneville clays using shelly tubes and piston samplers. The testing procedures employed during testing will be described and the results presented. Conclusions and recommendations based on the testing program will also be presented.

## ANALYTICAL MODELING OF MSE WALL

Measured soil properties, and wall geometry, will be incorporated into a finite element, or finite difference analytical model. The global deformations of the instrumented MSE wall can then be calculated using this model. The deformations obtained from the model will be compared to those actual deformations measured at the instrumented MSE wall.

MSE wall analysis conclusions and recommendations will be summarized in the MSE wall analysis report. Comparisons will be made between actual deformations measured at the instrumented MSE wall and deformations calculated in the model. The modeling procedures employed during the modeling will be described and the results presented. Conclusions and recommendations based on the modeling program will also be presented, and the recommendations highlighted.

## **DELIVERABLES**

Project deliverables will include the following:

1. Installation of instruments
2. Soil sampling
3. Report of installation
4. Sample disturbance Report
5. Monitoring Report (Year 1 and Year 2)
6. Final Analytical Report of MSE Wall

## STAFFING PLAN

The primary research team for this research study will include the following investigators from the Utah State University Department of Civil and Environmental Engineering:

Dr. James A. Bay, Principal Investigator  
Dr. Loren R. Anderson, Co Principal Investigator  
Dr. Joseph A. Caliendo, Co Principal Investigator  
Mr. Ken Jewkes, Technician

It is anticipated that several graduate and undergraduate students will participate in the project. Sensor installation, data collection and periodic servicing will be performed by UDOT research staff, in collaboration with Utah State University and in coordination with Wasatch Constructors. UDOT will also provide surveying equipment, a horizontal inclinometer, and a pressure cell readout device. UDOT Research personnel will also regularly monitor the instrumentation following construction. Drilling and sampling will require the services of a drilling contractor.

## SCHEDULE

The work schedule along with the proposed deliverables and payment schedule is presented in Table 3. This schedule assumes that construction of wall R-346-1C will begin near the end of September 1999. Delays in wall construction will put-off instrumentation activities for a similar interval.

**Table 3 Work Schedule with Deliverables and Payment Schedule**

Cumulative Lapsed Time	Activity	Deliverable
4 Weeks	Order sensors and supplies	None
8 Weeks	Install vertical and horizontal inclinometers in foundation, install horizontal inclinometer and pressure plates in foundation. Install monuments. Make benchmark readings and surveys on all installed instrumentation. Install strain gages on bar mats	Installed instruments in foundation and benchmarks data
12 Weeks	Install instrument bar mats in fill. Install horizontal and vertical inclinometers and extensometers in fill. Monitor all installed instrumentation during construction	Installed instruments in fill and construction data
26 Weeks	Monitor all instruments during post construction period. Turn monitoring duties over to U-DOT	Post Construction Data
34 Weeks	Prepare Final Instrumentation Report	Final Report

130 Weeks	Post Construction Monitoring	Monitoring Reports
6 Weeks	Soil Sampling	Samples
20 Weeks	Laboratory Testing	Test Data
28 Weeks	Prepare Final Sample Disturbance Report	Report
76 Weeks	Analytical Modeling of MSE Wall	Model
84 Weeks	Prepare Report of MSE Wall Analysis	Modeling Report

## BUDGET SUMMARY

### USU Contract Costs:

Personnel Direct Costs:	\$ 155,000
Equipment, Materials & Other Costs:	\$ 48,000
Subcontracts	<u>\$ 20,000</u>
<i>Subtotal Contract Direct Costs, Equipment Subcontractors Etc.:</i>	<i>\$ 223,000</i>
<i>Indirect USU Contract Costs:</i>	<i><u>\$ 22,300</u></i>
<i>Subtotal USU Contract Costs:</i>	<i>\$ 245,300</i>

### UDOT Direct Costs:

Personnel Direct Costs:	\$ 4,500
Equipment, Materials & Other Costs:	<u>\$ 1,200</u>
<i>Subtotal UDOT Direct Costs, Equipment Etc.:</i>	<i>\$ 5,700</i>

***Total Project Costs:*** ***\$ 251,000***



## 81F15309 - Corrosion Evaluation of Original I-15 Pipe Piles

Funding Source:	FHWA Research (TEA-21 FY 2000)	\$	0
	State Match (TEA-21 FY 2000)	\$	0
	FY 2001 SPR (Inc. State Match)	\$	<u>43,600</u>
	*Total Cost Estimate	\$	43,600
Principal Investigator:	Kyle M. Rollins		
Research Project Manager:	Sam Musser / Blaine Leonard		
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.			

### PROBLEM DEFINITION

Most of the overpass structures constructed on the I-15 corridor through Salt Lake Valley in the early to mid-60's were supported by steel pipe pile foundations. Typical soil conditions consist of soft clays and silts with a relatively high groundwater table. With the reconstruction of I-15 underway, essentially all of these foundations will be abandoned and new pile foundations are being constructed. This provides a unique opportunity to examine correlations between steel pile corrosion and soil and groundwater characteristics. Specimens of these abandoned piles, which have already been in the ground for 30 to 40 years, can be obtained and examined to determine the corrosion rate that has occurred. At the same time, information regarding soil type and moisture content as well as pH, resistivity, and ion concentration can be obtained from a sampling program. The results from this testing can then be used to quantify the degradation in steel section produced by long-term corrosion and to evaluate existing correlations for defining corrosive soil conditions. Results from this testing can also be directly applied in designing foundations for the new Legacy highway in Utah which will be constructed over soils similar to those at I-15.

### OBJECTIVES

The objectives of this research program are:

To quantify the effect of long term corrosion on steel pipe piles in cohesive soils.

To evaluate and improve correlations between corrosion and various soil and groundwater characteristics.

Provide additional well-documented data points on driven pile corrosion which can be used to validate/calibrate existing and future models.

### MAJOR TASKS

We anticipate that the work associated with this study can be accomplished with the following work tasks: (1) Conduct Literature Survey, (2) Select Test Site Locations for Extracting Specimens (3) Extract and Evaluate Test Specimens, (4) Characterize Soil and Groundwater, (5) Analyze Test Results and Evaluate Corrosion Prediction Guidelines, and (6) Prepare final report and Disseminate Results. Each of these work tasks is discussed in more detail below.

### 1. Conduct Literature Survey.

Although steel piles are commonly used in Utah and other western states, our preliminary review of the literature suggests that little information is available regarding long-term corrosion of piles in non-marine environments. However, a significant body of information is available on the performance of sewer pipes, corrugated culverts and storage tanks. Unfortunately, the available test data suggest that the potential for corrosion of piles may be significantly different than that for buried pipelines and storage tanks. Several organizations including AISI, AWWA, NBS, FHWA, and Caltrans, have developed guidelines for estimating the loss of thickness due to corrosion for culverts and storage tanks. The studies associated with each of these methods will be obtained as part of the literature survey for this study. In addition, a thorough computer search will be made to obtain available information on the topic from throughout the world. A summary of the available guidelines and corrosion estimation methods will be provided in the final report.

### 2. Select Test Site Locations for Extracting Specimens

In preparing this proposal, we have discussed the possibility of extracting piles using vibratory hammers with pile driving contractors. The contractors feel that the odds of success will be relatively low and mobilizing the crane to each site would be expensive. In addition, it would be necessary to demolish the pile cap prior to pulling the piles. Therefore, we propose to obtain test specimens by excavating below the pile caps and cutting sections from the steel shell. Although we would not be able to cut specimens more than a few feet below the watertable, this is also the most critical zone in terms of corrosion and in terms of axial load and lateral load on the piling.

To maximize the potential for successfully obtaining useful test specimens, a survey will be made to determine test site locations that meet several criteria. First, the sites should be located in silts and clays which are likely to produce more corrosive environments and are more typical of soils in Salt Lake Valley. In addition, it will be easier to de-water excavations in these low-permeability soils to obtain test specimens below the groundwater level. Second, the sites should be located where the groundwater is relatively shallow so that excavation down to the groundwater level can be accomplished without excessive cost and safety concerns. Lastly, the site should have a group of steel pipe piles and the soil profile and date of construction should be well known. Information of this type can be obtained from the original bridge plans and geotechnical records compiled by UDOT prior to the reconstruction of I-15. In addition, boring logs and soil test information from the geotechnical investigations performed for the I-15 reconstruction will be collected.

### 3. Extract and Evaluate Test Specimens.

At three or more sites, excavations will be made adjacent to pile caps and the steel pipe piles will be exposed. Excavations will be constructed to comply with safety regulations and will likely extend to a few feet below the groundwater level. The excavation will be pumped out and test specimens of the steel pipe will be obtained after a visual examination of the piling. We anticipate that it will be possible to cut away the steel shell from around the concrete fill using an



acetylene torch or an air arc torch. The pipe shell will be cut from two piles at each test site. The steel shell will extend from the base of the cap to a few feet below the original water table.

The steel sections will be returned to the laboratory and at various depths, test sections approximately 1 ft square will be saw cut. We anticipate that test specimens exhibiting varying degrees of corrosion will be obtained. These test specimens will be lightly sand-blasted or ground with wire brushes to remove the rust and then weighed to determine the average change in thickness due to corrosion. Visual inspection will also be performed and the depth of corrosion pits will be measured so that this can be related to the average thickness loss. Average thickness loss rather than corrosion penetration is more critical for piles.

#### 4. Characterize Soil and Groundwater.

In order to provide results which can be useful at other sites, we will obtain samples of soil and groundwater at depths corresponding to the location of the steel specimens. Field and laboratory testing will be performed to determine soil classification, moisture content, resistivity and pH as well as sulfate and calcium content. Previous research on steel pipe corrosion suggests that these factors are most important in predicting the corrosion rate. Excavating through the soil adjacent to the piles will make it possible to perform in-situ resistivity and pH measurements at various depths and to compare these measurements to lab test results which are thought to be less accurate. In addition, resistivity measurements will be made using cone penetration soundings which will provide a near continuous measurement of soil type and resistivity values. Perforated PVC monitoring pipes will also be installed to monitor the level of the groundwater at each test site during the course of a year. This information along with water level data from previous geotechnical investigations should provide an indication of the variability in the water level which might be anticipated.

#### 5. Analyze Test Results and Evaluate Corrosion Prediction Guidelines.

The soil property data will be used in the various equations and guidelines to predict the expected corrosion. The measured and computed corrosion rates will be compared to evaluate the accuracy of the various prediction methods. Modifications to the methods will be suggested if appropriate to improve the agreement. Correlations will also be developed between the corrosion rate and the various soil parameters to determine which factors appear to be most important. These parameters will then be used in a multivariate regression analysis to develop the best possible relationships based on a combination of the parameters.

#### 6. Prepare final report and Disseminate Results.

A final report will be prepared at the conclusion of this study. Two page quarterly reports will also be prepared to summarize the progress of the work. The final report will provide a detailed summary of the characteristics of the soil profile based on field and laboratory testing along with details regarding the measured pile corrosion. The test procedures employed in the testing will be described and the results presented. Conclusions based on the analysis of the available corrosion guidelines will also be presented along with suggested modifications and new equations. An executive summary will briefly summarize the investigation and highlight test

results that can be implemented in design procedures. The report and technical papers will be prepared for publication in appropriate engineering journals and conferences. We anticipate that presentations will also be made at TRB and ASCE meetings.

## DELIVERABLES

The following deliverables are expected from this project:

1. Extraction of samples
2. Site characterization
3. Final Report (Draft and Final versions)

## STAFFING PLAN

The Principal Investigator for this research project will be Dr. Kyle M. Rollins, of the Brigham Young University Department of Civil and Environmental Engineering. Dr. Rollins will be assisted by several graduate students. An excavating subcontractor will be employed to obtain the pile and soil samples.

## SCHEDULE

Activity	Apr-00	May-00	Jun-00	Jul-00	Aug-00	Sep-00	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01
Conduct Literature Survey												
Select Test Site Locations												
Extract and Evaluate Steel Specimens												
Characterize Soil and Groundwater												
Analyze Test Data/Evaluate Equations												
Preparation of Final Report												

## BUDGET SUMMARY

### BYU Contract Costs:

Personnel Direct Costs:	\$ 27,000
Equipment, Materials & Other Costs:	\$ 10,500
<i>Subtotal Contract Direct Costs, Equipment Etc.:</i>	<i>\$ 37,500</i>
<i>Indirect BYU Contract Costs:</i>	<i>\$ 3,750</i>
<i>Subtotal BYU Contract Costs:</i>	<i>\$ 41,250</i>

### UDOT Direct Costs:

Personnel Direct Costs:	\$ 2,200
Equipment, Materials & Other Costs:	\$ 150
<i>Subtotal UDOT Direct Costs, Equipment Etc. &amp; Subcontracts:</i>	<i>\$ 2,350</i>

***Total Project Costs:*** **\$ 43,600**

## 81F15310 - FULL-SCALE LATERAL PILE CAP AND BACKFILL LOAD TESTING

Funding Source:	FHWA Research (TEA-21 FY 2000)	\$ 33,159
	State Match (TEA-21 FY 2000)	\$ 8,290
	FY 2001 SPR with State match	<u>\$ 47,651</u>
	*Total Cost Estimate	\$ 89,100
Principal Investigator:	Kyle M. Rollins	
Research Project Manager:	Steven Bartlett / Blaine Leonard	
*Based on actual projected amounts for Research division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.		

### PROBLEM DEFINITION

Pile groups typically derive their lateral resistance due to four sources as shown in Fig. 1, namely: (1) pile-soil-pile interaction, (2) passive pressure resistance on the pile cap, (3) base friction on the pile cap, and (4) side-friction on the pile cap. As a result of research funded during the first year of the I-15 test bed program, we now have four pile groups constructed at South Temple. All the pile groups have been tested statically under free-head conditions and two of the pile groups have also been tested dynamically using the Statnamic technique. The goal of the 1<sup>st</sup> year study has been to evaluate pile-soil-pile interaction as a function of pile spacing. In addition, Prof. Lawton at the Univ. of Utah has already performed a lateral load test on a large concrete block (8'x24'x3') to evaluate base friction. Caltrans and other reviewers have noted that pile groups normally have pile caps and suggested that we perform follow-on testing of the pile groups after construction of a pile cap. Testing would be performed with and without backfill behind the cap. This is a natural progression for the testing program which can pay high dividends with relatively modest additional cost. Similar research at the Salt Lake Airport site showed that passive pressure provided as much as 40% of the total resistance of the 9 pile group.

Finally, during testing of the 15 pile (3 piles on 5 rows) group, the reaction force provided by the adjacent geopier cap block was insufficient to produce deflections greater than about 1.25 inches. Subsequent statnamic load testing produced deflections of about 4 inches. In order to provide a better comparison between the static and dynamic load-deflection curves over a greater deflection range, additional reaction piles behind the geopier cap block and additional static load tests will be performed

## **OBJECTIVES**

The objectives of this research program are:

1. To define the effect of pile cap restraint on pile-soil-pile interaction and group reduction factors.
2. To evaluate available methods for predicting passive pressure on pile caps and to define the movements necessary to develop the ultimate pressures.
3. To evaluate the reduction in passive pressure resistance as a function of load cycles.
4. To provide comparison between static and dynamic lateral load resistance.
5. To provide well-documented case histories which can be used to validate/calibrate existing and future computer models

## **MAJOR TASKS**

1. Construct additional pile cap over the 3x3 pile group with 24" diameter piles.

A reinforced concrete pile cap (11'x18' x4') is already in place over a group of twelve 12.75" OD pipe piles. We propose to construct an additional reinforced concrete pile cap over an adjacent group of nine 24" OD pipe piles. The new cap would measure (18'x18'x4'). Prior to placement of the cap, the pipe piles, which were driven open-ended, will be drilled out and filled with reinforced concrete. Inclinometer pipes will be installed down the center of each pile. The two pile cap foundations will then be in position to react against each other for subsequent lateral pile group load tests.

2. Conduct cyclic lateral load tests without backfill.

Prior to placement of backfill, the pile groups will be loaded for at least 5 cycles using two 500 ton hydraulic jacks placed between the two pile caps. Load will be applied in approximately 10 load increments. Load will be measured using load cells and deflection will be measured using LVDTs. Although the two pile groups have been previously tested under free-head conditions, testing was performed by pulling the pile groups together. After the additional pile cap is constructed, the pile groups can be loaded in essentially virgin soil conditions by pushing the pile caps apart. The 24" OD piles have already been instrumented with strain gauges in the direction of loading. Strain gauges are placed at opposite faces at 10 depth levels so that the bending moment versus depth curve can be accurately defined. Both pile groups will also have inclinometer pipes installed in piles in each row of the group. Inclinometer readings will be taken at each load increment so that the horizontal deflection versus depth can be determined. Inclinometer data will also be used to obtain bending moment versus depth curves to compare with the curves derived from the strain gage data. All data will be recorded with a Megadac computer data acquisition system.

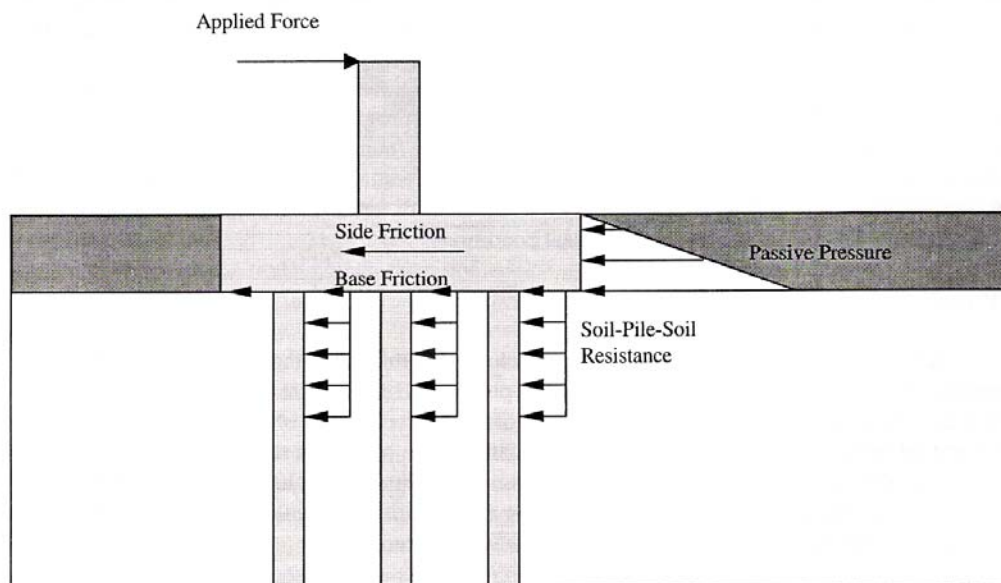
This set of tests will make it possible to compare the behavior of the pile groups with and without a pile cap in place. In addition, they will serve as a baseline for use in determining the passive force in comparison with results from the subsequent set of tests.

### 3. Conduct cyclic lateral load test with backfill.

Prior to performing the second set of tests, backfill will be placed behind the back face of each pile cap. It is anticipated that a clean sand will be placed behind one cap and a silty sand or sandy silt will be placed behind the other. The soil will be placed at 90% of the modified proctor maximum density and density tests will be performed on each lift during compaction. The load tests will then be carried out using essentially the same testing set-up as employed previously. At least 5 cycles of load application will be applied at each load increment to define any degradation in passive pressure due to potential gapping between the pile cap and the backfill soil. After completion of the testing, in-situ direct shear tests will be performed on each backfill soil to better define the strength properties at low confining pressures. Cone penetration and SPT testing will also be performed on the backfill soil.

### 4. Conduct Static Lateral Load Test on 15 Pile Group.

In order to provide an adequate reaction for the 15 pile group, four large diameter drilled shafts will be constructed adjacent to the pile group. Load will be applied to the group using two 150-ton hydraulic jacks and deflection will be measured using LVDT's. Strain gauges are already attached to one pile in each of the 5 rows of the group to provide bending moment information. Load will be applied in 8 to 10 load increments and 15 load cycles will be applied for each load



**Figure 1 – Schematic drawing showing contribution of soil-pile-soil resistance, passive pressure, base friction, and side friction to lateral resistance provided by a pile group.**

increment. Load will be increased until a deflection of approximately 4 inches is reached. This will make it possible to compare the static load-deflection curve with the dynamic load-deflection curve previously obtained with the statnamic load system. Knowing the static and dynamic load-deflection curves, the damping coefficient for the system can be back-calculated.

#### 5. Reduce and Analyze Test Results.

The results from the testing program will be reduced and at least the following graphs will be prepared:

- Average pile head load versus deflection curves for the first and last cycle for each group.
- Maximum bending moment versus applied load as a function of load cycle for each group.
- Bending moment versus depth curves for each load increment for each pile group.
- Lateral deflection versus depth curves for each load increment for each pile group.
- Comparison plots between free-head and restrained-head pile groups.
- Passive force development for each soil type as a function of deflection.
- Variation of passive force development as a function of gap formation.

Finally, studies will be conducted to evaluate the ability of computer programs for analyzing laterally loaded piles and pile groups to match the behavior observed in the testing. We anticipate using the programs LPILE/GROUP (Reese et al, 1996) and FLPIER (Florida Dept. of Trans., 1996). The GROUP program uses the finite difference method and is widely used in practice. The FLPIER program uses the finite element method and was developed by McVay and his co-workers at the Univ. of Florida. This program is distributed by the Florida DOT at minimal cost and will likely see increased use as a result of FHWA support. Both of these programs employ the p-y concept and allow the user to define p-multipliers. These programs were found to provide reasonable estimates of the lateral load behavior of the pile group in the previous testing program. Validation studies of this type are crucial in providing designers and researchers with "ground truth" information regarding the ability of computer programs to model real conditions.

#### 6. Prepare final report and Disseminate Results.

A final report will be prepared at the conclusion of this study that will be provided to the sponsors. Two page quarterly reports will also be prepared to summarize the progress of the work. The final report will provide a detailed summary of the characteristics of the soil profile based on field and laboratory testing along with details regarding the pile properties. The test procedures employed in the testing will be described and the results presented. Conclusions based on the testing program will also be presented. An executive summary will briefly summarize the investigation and highlight test results that can be implemented in design procedures.

The report and technical papers will be prepared for publication in appropriate engineering journals and conferences. We anticipate that presentations will be made at the TRB meeting and the AASHTO Bridge Committee meetings. In addition, digital results from this testing program will be distributed on CD's so that interested researchers desiring to use other computer models will have a detailed record of all test results.

## DELIVERABLES

The following deliverables are anticipated as part of this research project:

1. Construction of a Pile Cap and Drilled Shafts
2. Completion of Field Testing
3. Final Report (Draft and Final versions)

## STAFFING PLAN

The Principal Investigator for this research project will be Dr. Kyle M. Rollins, of the Brigham Young University Department of Civil and Environmental Engineering. Dr. Rollins will be assisted by several graduate students. An excavating subcontractor will be used for pile cap construction, drilled shaft construction, and soil excavation and compaction.

## SCHEDULE

A tentative schedule for the completion of the work tasks discussed previously is shown below. This schedule assumes that the testing can be performed after demolition of the bridge and during construction operations. If this is not the case, the testing schedule will have to be accelerated.

Activity	Apr-00	May-00	Jun-00	Jul-00	Aug-00	Sep-00	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01
Construct Pile Cap	■	■										
Load Test without Backfill		■										
Backfill Placement			■									
Load Test with Backfill			■									
Backfill Property Characterization				■								
Static Load Test with 15 pile Group				■								
Data Reduction and Analysis				■	■	■	■	■	■	■		
Preparation of Final Report									■	■	■	■

## BUDGET SUMMARY

### **BYU Contract Costs:**

Personnel Direct Costs:	\$ 34,000
Equipment, Materials & Other Costs:	\$ 11,400
Subcontracts:	<u>\$ 31,000</u>
<i>Subtotal Contract Direct Costs, Equipment Etc. &amp; Subcontracts:</i>	<i>\$ 76,400</i>
<i>Indirect BYU Contract Costs:</i>	<i><u>\$ 7,600</u></i>
<i>Subtotal BYU Contract Costs:</i>	<i>\$ 84,000</i>

### **UDOT Direct Costs:**

Personnel Direct Costs:	\$ 4,400
Equipment, Materials & Other Costs:	<u>\$ 300</u>
<i>Subtotal UDOT Direct Costs, Equipment Etc.:</i>	<i>\$ 4,700</i>

<b><i>Total Project Costs:</i></b>	<b><i>\$ 88,700</i></b>
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